**BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA**

Order Instituting Rulemaking to Further Develop A Risk-Based Decision-Making Framework for Electric and Gas Utilities.	Rulemaking R.20-07-013 (Filed July 16, 2020)

MUSSEY GRADE ROAD ALLIANCE ADDITIONAL COMMENTS REGARDING

DEVELOPMENT OF SAFETY AND OPERATIONAL METRICS

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Dated: March 1, 2021

1. INTRODUCTION

Pursuant to February 1, 2021 Email Ruling by Administrative Law Judge Fogel requesting additional comment on safety and operational metrics (Ruling),[1] the Mussey Grade Road Alliance (MGRA or Alliance) files additional comments and information regarding issues raised in the Ruling.

Comments were prepared by Alliance expert Joseph W. Mitchell, Ph.D.

2. BACKGROUND

Parties, including MGRA,[2] filed comments on PG&E's proposed Safety and Operational Metrics proposal.[3] Additionally, a workshop was held on January 28, 2021 during which PG&E's SOM proposal was discussed and parties had an opportunity to ask questions and raise issues with PG&E's proposal. On February 1st, ALJ Fogel issued her ruling requesting additional comment. The Ruling states in part:

"*At the January 28, 2021 workshop, parties to R.20-07-013 requested additional time to file more thoughtfully considered comments on PG&E's January 15, 2021 filing. To accommodate this, parties to R.20-07-013 shall file additional comments on PG&E's proposed SOMs and on topics discussed at the January 28, 2021 workshop no later than March 1, 2021.*

In their comments, parties may propose modifications to PG&E's proposed metrics as well as alternative and additional metrics to those proposed by PG&E, and may provide additional context, information, and commentary on PG&E's proposal. Please address the question of whether and in what instances the granularity of reported metrics should correspond to tranches used to define risks and risk mitigations. Further, we request that parties provide input on the

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[1] R.20-07-013; Email Ruling Requesting Additional Information and Party Comments; February 1, 2021. (Ruling)

[2] R.20-07-013; MUSSEY GRADE ROAD ALLIANCE REPLY TO THE RESPONSE OF PACIFIC GAS AND ELECTRIC COMPANY REGARDING DEVELOPMENT OF SAFETY AND OPERATIONAL METRICS; January 25, 2021. (MGRA Comments)

[3] R.20-07-013; RESPONSE OF PACIFIC GAS AND ELECTRIC COMPANY TO ASSIGNED COMMISSIONER'S RULING REGARDING DEVELOPMENT OF SAFETY AND OPERATIONAL METRICS; January 15, 2021. (SOM Proposal).

development of "operational metrics." Do parties agree with the list provided by PG&E and PG&E's reasoning for proposing metrics that are safety related with an operational component rather than purely operational metrics? Please provide additional comments or proposals on this this topic.

Finally, in their January 25, 2021 comments, The Utility Reform Network (TURN) requested that parties be directed to begin to explore potential targets for PG&E's proposed SOMs both as triggers for the Enhanced Oversight and Enforcement process outlined in D.20-05-053 and to compare utility safety results. Several parties noted the relationship between appropriate targets or triggers and potential negative "managing to the metric" practices. We concur with TURN that it would be worthwhile for parties to begin to explore potential targets for PG&E's proposed SOMs. We invite parties to begin to address this topic in the additional comments authorized in this ruling as well as in subsequent Track 2 technical working group meetings."

3. ISSUES

MGRA's Comments[4] presented MGRA's position on PG&E's SOM Proposal. Briefly stated, MGRA finds PG&E's proposed wildfire metrics wholly inadequate for tracking wildfire risk or serving as triggers for PG&E's Enhanced Oversight and Enforcement Process. MGRA proposed additional "resiliency" metrics including risk events, and supported collection of supplemental weather data to normalize for year-to-year and utility-to-utility differences in weather stress that can lead to ignitions.

MGRA will be responding to the following topics raised in ALJ Fogel's Ruling:

- *…modifications to PG&E's proposed metrics as well as alternative and additional metrics to those proposed by PG&E, and … additional context, information, and commentary on PG&E's proposal,*
- *…whether and in what instances the granularity of reported metrics should correspond to tranches used to define risks and risk mitigations,*
- *… development of "operational metrics,"*
- *… potential targets for PG&E's proposed SOMs*

[4] MGRA's comments were originally filed on the 25th of January, but were rejected due to a filing error on MGRA's part. MGRA late-filed these comments on February 17, 2021.

As in our original comment, MGRA is only responding to the wildfire risk element in PG&E's SOM Proposal.

3.1. Alternative Metrics

MGRA's Comments list a number of additional metrics, specifically:

- Risk events
- Outages due to vegetation and equipment damage
- Damage during PSPS events

The Comments also caution that the metrics proposed by PG&E will be biased by the application of PSPS. MGRA suggests tracking weather metrics as a way of normalizing ignition, wires down, risk events, outages, and PSPS damage.

One metric that can be used as a simple proxy for weather data is whether events occur during and within the boundaries of National Weather Service High Wind Warnings (HWW), High Wind Advisory (HWA), and Red Flag Warning (RFW) areas. MGRA is investigating these metrics as part of its 2021 Wildfire Mitigation Plan review. These metrics are not ideal. They are binary (in place or not in place), and do not differentiate between severe, extreme, and critical conditions. However, they can provide a baseline that can be compared across utilities. Utilities are also required to report number of utility mile-days that their infrastructure spends under HWW and RFW conditions, which allows some degree of normalization.

3.2. Metrics and Tranches

On February 3, 2021, MGRA presented a technical white paper and slide presentation[5] regarding the implications and use of power laws to represent wildfire size distributions. The white paper and presentation are attached as Appendix A and B of these comments. The MGRA white paper is directly applicable to the question of metrics and tranches because it proposes dividing risk

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[5] Technical White Paper – Appendix A; Slide Presentation – Appendix B
WILDFIRE STATISTICS AND THE USE OF POWER LAWS FOR POWER LINE FIRE PREVENTION FINAL: FEBRUARY 11, 2021; Joseph W. Mitchell, Ph.D. for the Mussey Grade Road Alliance.

events into tranches according to the strength of the weather event in place at the time. Each tranche is designed to correspond to a weather severity level at which the utility can safely operate without resorting to PSPS. These tranches can be applied at the circuit or segment level. In this model, the goal of utility wildfire mitigation is to apply mitigation to the lowest risk tranche for which PSPS is the current mitigation and harden it so that it can tolerate the conditions associated with that tranche. The lowest tranche corresponds to the "baseline" ignition and fire rate that is not associated with external stressors on the system.

The advantage of the proposed MGRA is that it classifies risk events according to the conditions under which they occur, with the most severe consequences much more likely under the most extreme conditions. It acknowledges that PSPS will be the mitigation for the most extreme conditions, but lays out a framework for eliminating the risk and harm from PSPS under less extreme conditions.

A number of parties provided feedback on the MGRA proposal. Cal Advocates and PG&E were generally in favor of the proposal, SCE, TURN, and UCAN generally opposed it, and SDG&E thought more investigation was necessary. In its own post-workshop comments, MGRA emphasized the importance of using statistical methods that correctly weight the contribution of extreme events, which dominate losses for wildfires. MGRA's proposal for using a power law description for wildfire consequence distributions fits this requirement, and there is significant scientific work supporting use of power laws for wildfire. MGRA urges further discussion of its proposal during the current and subsequent phases of this proceeding.

3.3. Operational Metrics

With regard to wildfire, the only "operational" metrics that would be relevant to safe utility operation would have to do with the protocols surrounding power shutoff. Other metrics, such as risk events, wires down, or ignitions are trailing metrics not under the utilities' direct control. With regard to power shutoff, the Commission might want to consider the following:

- Does the utility have specific shutoff criteria on a circuit-by-circuit (or finer) basis, and are these criteria transparently stated?
- For a given risk event, did the utility adhere to its shutoff criteria; i.e. did the measured weather conditions exceed the thresholds?

- Are shutoff thresholds consistent with real risk of either vegetation contact or damage to equipment from wind gusts exceeding GO 95 design criteria?
- Did the utility's weather measurements correspond to its forecasts?
- Did the utility notify all required customers and partners regarding de-energization and re-energization on a timely basis?

Many of these factors are (or are supposed to be) included in post-event reporting by the utility. However, neither the Commission nor SED have provided "reasonableness" evaluations on a regular basis that would allow the utility reports to be used as metrics. The Commission may want to consider a more rigorous and regular review of the utility post-event reports, and the creation of specific operational metrics that can be tracked and compared across utilities.

3.4. Potential Targets for Safety and Operational Metrics

The proposed safety and operational metrics relevant to wildfire are trailing indicators, and at some level are a function of external events as well as any inherent utility vulnerabilities. Establishing specific numerical targets will additionally require that existing baselines be determined, vetted, and compared between utilities.

It is possible, however, to specify "things that should not happen" as SOM targets while numerical targets are being developed. Specific targets of this type might include:

- Utility circuits are only de-energized when well-defined triggering threshold criteria are met. Any exceptions should be fully reviewed.
- No utility wildfire ignitions occur during critical fire risk days in HFTD areas. Of course, such a target would need to be carefully evaluated, because it rather begs for a PSPS solution. It would need to be coupled with a corresponding PSPS metric such as the previous item.

4. CONCLUSION

MGRA appreciates the opportunity to provide additional comment on the Safety and Operational Metrics and looks forward to continued collaboration with S-MAP parties and stakeholders.

Respectfully submitted this 1st day of March, 2021,

By: __/S/____***Diane Conklin***____________________

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Appendix A – White Paper – Wildfire Statistics and Power Laws

BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

Application of Pacific Gas and Electric Company (U 39 M) to Submit Its 2020 Risk Assessment and Mitigation Phase Report	Application A.20-06-012 (Filed June 30, 2020)

WILDFIRE STATISTICS AND THE USE OF POWER LAWS FOR POWER LINE FIRE PREVENTION

FINAL: FEBRUARY 11, 2021

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Dated: February 11, 2021

Table of Contents

1. INTRODUCTION

This whitepaper has been prepared by Mussey Grade Road Alliance (MGRA) expert Joseph Mitchell, Ph.D. at the request of the Safety Policy Division (SPD) to provide a technical proposal for the use of power laws for utility risk calculations in the S-MAP proceeding R.20-07-013.

The goal of this whitepaper is to provide a starting point for practical and accurate wildfire risk calculations that can be incorporated into utility Risk Assessment Mitigation Plan (RAMP) proceedings and used to prioritize utility mitigation strategies. To do this this paper will first to lay out the basic principles of wildfire statistics based on current scientific measurements and estimates. It will then attempt to lay out possible methods by which these principles can be incorporated into the multi-attribute value function (MAVF) as required by the S-MAP Settlement Agreement. The aim of any such effort should be useability and not scientific elegance. While precision is nice, due to the nature of extreme event statistics it is possible to be very precise over certain ranges and to miss the big picture entirely.

Utility wildfire ignitions are driven primarily by extreme weather events, both in their frequency and consequences. While wildfire size is driven by the severity of weather events, utility wildfire frequency is driven both by the frequency of extreme weather events and their severity. This is because extreme weather events, and specifically extreme winds, cause non-linear increases in infrastructure damage, both direct and from flying debris and falling trees. Correct utility wildfire statistics therefore requires correct weather statistics, and there is considerable uncertainty regarding these. There is also still a good degree of uncertainty in the California wildfire size distribution statistics themselves, if not in their overall behavior then in the extreme tail ends of the distributions – which is where they really count. This will have big implications for some more extreme forms of mitigation – undergrounding of distribution lines, for instance, but not much so for other forms of mitigation such as hardening and EVM. This is because the utility go-to mitigation for extreme events (and not so extreme) has become de-energization, or "public safety power shutoff" (PSPS). If correctly applied (timing and extent), de-energization can be effective in stopping utility ignition of wildfires, and more certain in its outcome than other mitigation measures. However, as has been raised in numerous Commission proceedings, de-energization comes with a slew of public harms and increased risks, including some risks that also scale with weather event severity (such as the potential for ignitions from generators and cooking fires escaping into the wildland urban interface). PSPS is both a risk and a mitigation, and its harms need to be quantified as well as its benefits. Hence, risk-spend efficiencies for most mitigations are not so much to balance their costs against potential avoided wildfire harm as they are to balance their costs against PSPS harm. This can all be summarized in the following principle:

The purpose of utility wildfire mitigation is to raise the fire weather severity limits at which utility equipment can be safely operated.

In other words, PSPS can save Californians from harm due to catastrophic wildfire. Mitigation can save Californians from harm due to PSPS.

2. POWER LAWS AND WILDFIRE

Power laws are a class of statistical distributions that follow "scaling" or "self-similar" distributions over many orders of magnitude. If two variables are related by a power law, then the increase or decrease of the magnitude of one variable will be proportional to the increase or decrease in the magnitude of the other variable. Mathematically this is shown as:

$$y = Cx^{-\alpha}$$

These are often plotted on log-log plots, since this demonstrates the linear relationship between the scales:

$$\log y = -\alpha \log x + \log C$$

Power laws are observed in numerous disciplines: physics, economics, information technology, sociology, biology, ecology, urban planning, to name some. While some power laws are direct manifestations of physical laws (for instance Kepler's Law in astronomy), some power law relationships arise spontaneously from interrelationships between system components, or are "self-organized". This has led to an entire discipline of "complexity science" that attempts to explain phenomena as a result of universal scaling laws. The literature on this topic is extensive, including not only academic articles but numerous books, including popular treatments.[1] Per Bak, one of its founders explained that "complex behavior in nature reflects the tendency of large systems with many components to evolve into a poised, 'critical' state, way out of balance, where minor disturbances may lead to events, called avalanches, of all sizes. Most of the changes take place through catastrophic events rather than by following a smooth gradual path."[2]

2.1. Fat-Tailed Distributions

Power laws are an example of "fat-tailed" distributions, in which the overall weight of the distribution is dominated by rare or even extreme events. In fact, for certain values of the exponent ($\alpha < 2$) the integral of the power law (used for weighting probabilities) does not converge, which means that the contributions from extreme events will always dominate the results.[3] The mean, if calculated, becomes larger the more events are included in the distribution, so it is impossible to predict the mean accurately based on any amount of past data. Contributions from future events will always be larger (in the long run) than those from past events.

Another important consideration with fat-tailed distributions is uncertainty. Out on the tail of the distribution the statistical uncertainty is larger, as well as the potential for systematic uncertainties, such as effects driven by rare and as yet unmeasured phenomena. Because of the overweighted contribution of the extreme tail to the overall result, these uncertainties can have a significant or even dominant effect. You know the least about what you need to know the most.

There are "fat-tailed" distributions other than power laws, such as lognormal and related distributions. In fact, in many cases these distributions fit data traditionally associated with power laws better than a power law distribution.[4] Which are more appropriate for wildfire size distributions is discussed below.

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[1] For example, "Scale: The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organisms, Cities, Economies, and Companies", by Geoffrey West; 2017; Penguin Press.
[2] Bak, P., 1999. How Nature Works: the science of self-organized criticality, First Softcover edition. ed. Copernicus, New York.
[3] Newman, M.E.J., 2005. Power laws, Pareto distributions and Zipf's law. Contemporary Physics 46, 323–351. https://doi.org/10.1080/00107510500052444
[4] Benguigui, L., Marinov, M., 2015. A classification of natural and social distributions Part one: the descriptions. arXiv preprint arXiv:1507.03408.

2.2. Wildfire Size Distributions and Power Laws

Wildfire sizes are among the first natural hazard phenomena to be characterized as power law distributions. Malamud, Morein and Turcotte's pioneering work in 1998[5] found scaling behavior when looking at a variety of data sets. This work and others[6] also demonstrate that the power law behavior can be generated by simple toy models of wildfire ignition, such as cellular automata.

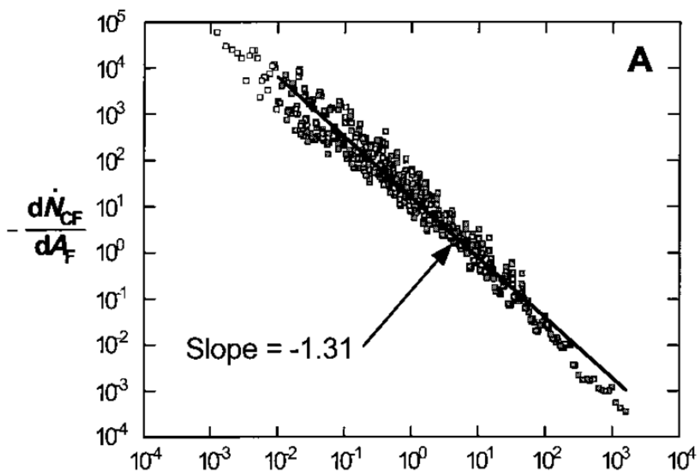

Figure 1 - Example wildfire size distribution from Malamud, et. al. (Reference 5). This distribution shows wildfire sizes in km^2 (horizontal axis) from US Fish and Wildlife Service lands from 1986 to 1995. The data are plotted as a non-cumulative distribution, in which the y axis value represents the total number of fires within a particular size bin. Power laws show a linear distribution when plotted on a log-log plot.

This relationship was studied by other authors as well. Some authors such as Beguini and Marinov[7] confirmed the direct power law relationship. Others, using different reference data, such as Newman,[8] which uses a larger data set, shows an apparent truncation in the data, which he asserts "could follow a power law but with an exponential cutoff".

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[5] Malamud, B.D., Morein, G., Turcotte, D.L., 1998. Forest Fires: An Example of Self-Organized Critical Behavior. Science 281, 1840–1842. https://doi.org/10.1126/science.281.5384.1840

[6] Turcotte, D.L., Malamud, B.D., Guzzetti, F., Reichenbach, P., 2002. Self-organization, the cascade model, and natural hazards. PNAS 99, 2530–2537. https://doi.org/10.1073/pnas.012582199 https://www.pnas.org/content/99/suppl_1/2530
Drossel, B., Schwabl, F., 1992. Self-organized critical forest-fire model. Phys. Rev. Lett. 69, 1629–1632. https://doi.org/10.1103/PhysRevLett.69.1629

[7] Benguini and Marinov, 2015; Reference 4.

[8] Newman, M.E.J., 2005. Power laws, Pareto distributions and Zipf's law. Contemporary Physics 46, 323–351. https://doi.org/10.1080/00107510500052444

2.3. Wildfire sizes in California

We are naturally most concerned with wildfire sizes in California. Several authors have looked at this question. Moritz et. al. examined data from the Los Padres National Forest and found that scaling of wildfire sizes followed a power law with exponent of α = 0.5. They used a "highly optimized tolerance" (HOT) probability loss resource (PLR) model to fit the data, which incorporates deviation from power law behavior at both low and high size limits:

$$y = C[(a + x)^{-\alpha} - (a + L)^{-\alpha}]$$

where a is the small size cutoff and L is the large size cutoff.[9]

In Mitchell 2009,[10] the following distribution for all fires in Southern California between 1960 and was shown:

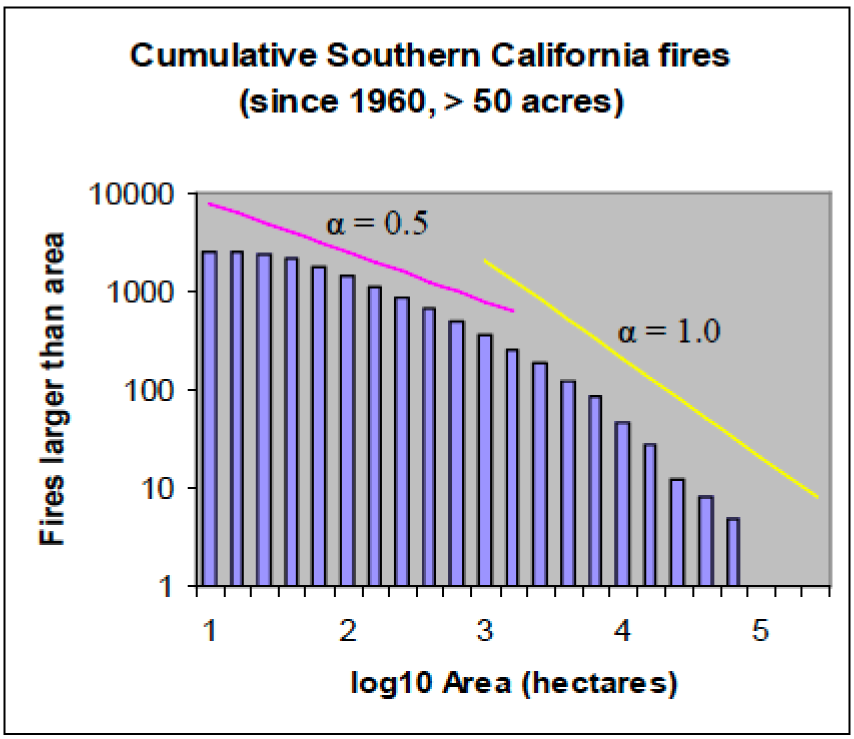

Figure 2 - Reproduced from Mitchell 2009, Fire and Materials. Different power law slopes are seen over different size domains. Unlike Malamud, et al., this plot uses a cumulative distribution, in which the vertical axis shows the total

[9] Moritz, M.A., Morais, M.E., Summerell, L.A., Carlson, J.M., Doyle, J., 2005. Wildfires, complexity, and highly optimized tolerance. Proceedings of the National Academy of Sciences 102, 17912–17917. https://doi.org/10.1073/pnas.0508985102

[10] Mitchell, J.W., 2009. Power lines and catastrophic wildland fire in southern California, in: Proceedings of the 11th International Conference on Fire and Materials, pp. 225–238.

number of wildfires larger than the value on the horizontal axis. The exponent for a cumulative distribution is one less than the exponent for a non-cumulative distribution.

Rather than a cutoff, this figure shows a steadily increasing slope as fire size increases.

Clauset, et. al.[11] looked at all fires in California and determined that the behavior could be described by a power law with an exponential cutoff. This would be of the mathematical form:

$$y = Cx^{-\alpha}e^{-\lambda x}$$

In summary, there is general agreement that power law distributions can be used to describe wildfire sizes in California over a certain range of scales. Behavior of wildfire statistics for the largest events, which are extremely important for risk estimation, shows a good deal of variation from study to study and should be regarded as an open question.

2.4. Fire Weather Severity and Wildfire Size Distributions

Fire weather conditions are known to be a driver of the ultimate size of wildfires, but this topic has received less study than geographic variations. One exception is the work of Boer, et. al.,[12] who examined wildfires in Australia and determined that "fire sizes and fire weather events were found to have matching scaling behaviour over a considerable, yet restricted, range of fire sizes, corresponding to roughly 50–60% of the recorded fires. Thus, other fire-controlling factors than weather including fuel patterns may still determine the distribution of a significant proportion of the (smaller) fires but, as our findings suggest, they do not explain the spatial scale invariance of the fires in our study areas." In other words, extremely large fires are more probable during extreme fire weather. More recently, Abatzoglu, et. al. showed that human-related ignitions concurrent with high winds lead to larger fires.[13]

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[11] Clauset, A., Shalizi, C.R., Newman, M.E.J., 2009. Power-Law Distributions in Empirical Data. SIAM Rev. 51, 661–703. https://doi.org/10.1137/070710111

[12] Boer, M.M., Sadler, R.J., Bradstock, R.A., Gill, A.M., Grierson, P.F., 2008. Spatial scale invariance of southern Australian forest fires mirrors the scaling behaviour of fire-driving weather events. Landscape Ecol 23, 899–913. https://doi.org/10.1007/s10980-008-9260-5
https://research-repository.uwa.edu.au/files/1480533/11732_PID11732.pdf

[13] Abatzoglou, J.T., Balch, J.K., Bradley, B.A., Kolden, C.A., 2018. Human-related ignitions concurrent with high winds promote large wildfires across the USA. International Journal of Wildland Fire. https://doi.org/10.1071/WF17149
http://www.pyrogeographer.com/uploads/1/6/4/8/16481944/abatzoglou_etal_2018_ijwf.pdf

2.5. Utility Wildfires are Larger

The factor makes utility wildfires unique is that one of the drivers that leads to larger wildfires – extreme weather – also makes ignition more probable. This changes the shape of the fire size distribution, as I observed in Mitchell 2009's plot of utility wildfire sizes.[14]

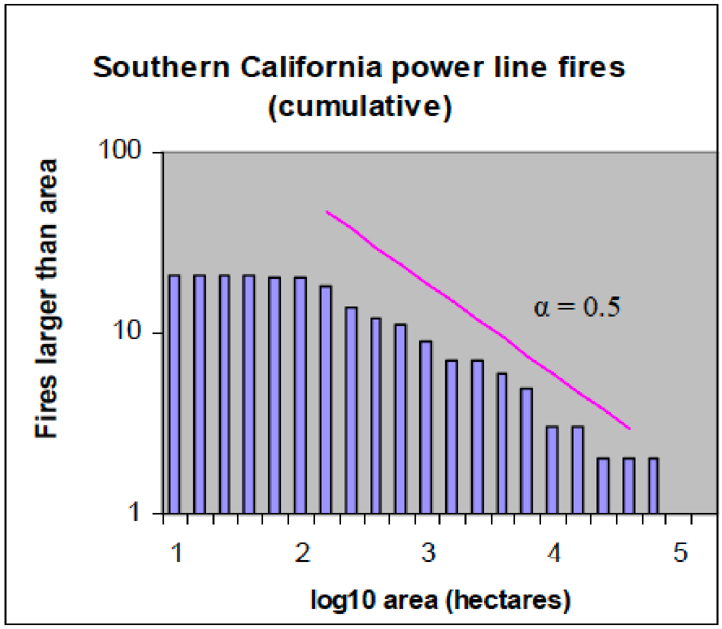

Figure 3 - Reproduced from Mitchell 2009. This figure, a cumulative distribution, shows that the tail of extreme power line events is broad, based on the shallow slope in the log/log plot.

While the sample size was small for this plot, it shows that the slope of the log-log plot is shallow, indicating an inordinate contribution from very large events. As Mitchell 2009 also noted, sampling fire events that start during extreme fire weather also produces a distribution that is skewed to large fires, and power line fires tend to start during extreme weather events. That is the fundamental reason for over-representation of utility fires as catastrophic events: Fires are more likely to be ignited at the very times when fire growth is likely to be largest.

The 2009 data set was small, and below we review the same approach using CAL FIRE's perimeter data set updated to the end of 2019. The cause attribution in the data set is sometimes incorrect or ambiguous ("unknown") in the case of disputed catastrophic fires. These were corrected

[14] Mitchell 2009; Footnote 10.

with attributions later found in CAL FIRE incident reports and SED CPUC reviews. Two subsets of the data are shown: without power line fires and power line fires only.

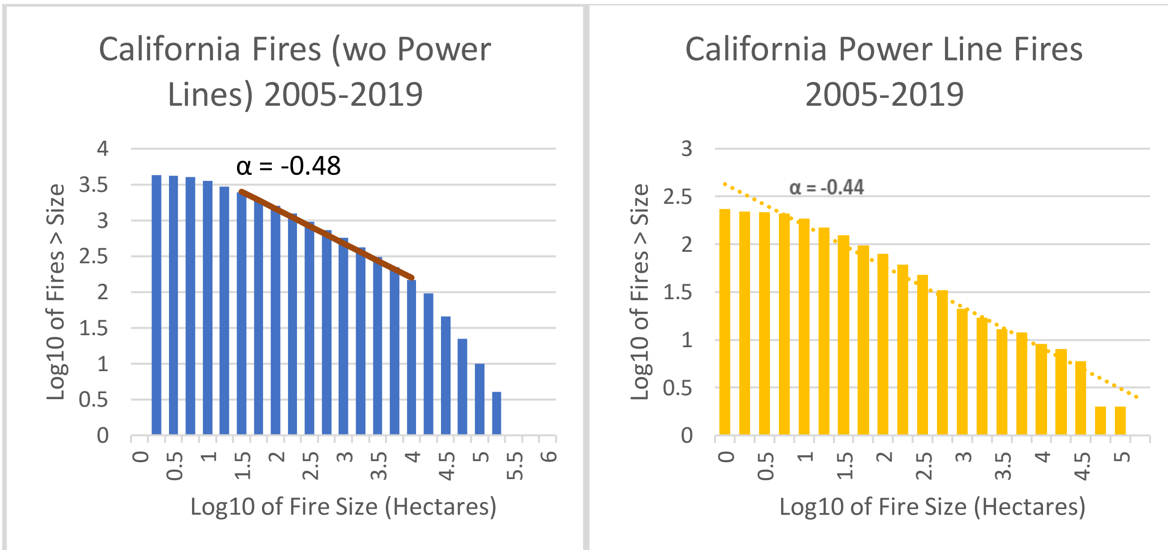

Figure 4 - CAL FIRE perimeter data for wildfires attributed to power line ignitions, shown as cumulative distributions plotted on log-log axes. 2007 and 2017 fire attributions are corrected with CAL FIRE and CPUC assessments. The trendlines are a guide to the eye, rather than a best fit and shows how power line exponents would appear. These are extreme fat-tailed distributions. Deviations from power law behavior appear above 30,000 acres (without power lines) and 80,000 acres for power line fires. Maximum scale may be 500,000 acres, with large uncertainty.

Trendlines are plotted and serves as a guide to the eye.[15] For wildfires with power line fires excluded a power law with exponent of -0.48 would describe the data over 3 orders of magnitude. For power line fires, a power law with exponent of -0.44 would fit the data over 3.5 orders of magnitude. Both distributions show a drop off, with non-power line fires deviating from power law above 30,000 acres and power line fires deviating over 80,000 acres. Statistics are poor and uncertainties large for the largest fires, but data would be consistent with a maximum size scale on the order of 500,000 acres for California fires. The exponent is very small (much less than 1.0) indicating that California wildfires exhibit extreme fat-tailed behavior.

[15] As per Clausset 2009 (Footnote 11), least squares methods are prone to bias by tail statistics and a maximum likelihood method should be employed to obtain accurate power law exponents.

What are the implications of this fat-tailed behavior for risk management? We can reformulate the above plots to show total loss (hectares burned) for each of the size bins. This is done by multiplying the number of events in each bin by mean size of each (logarithmic) bin.

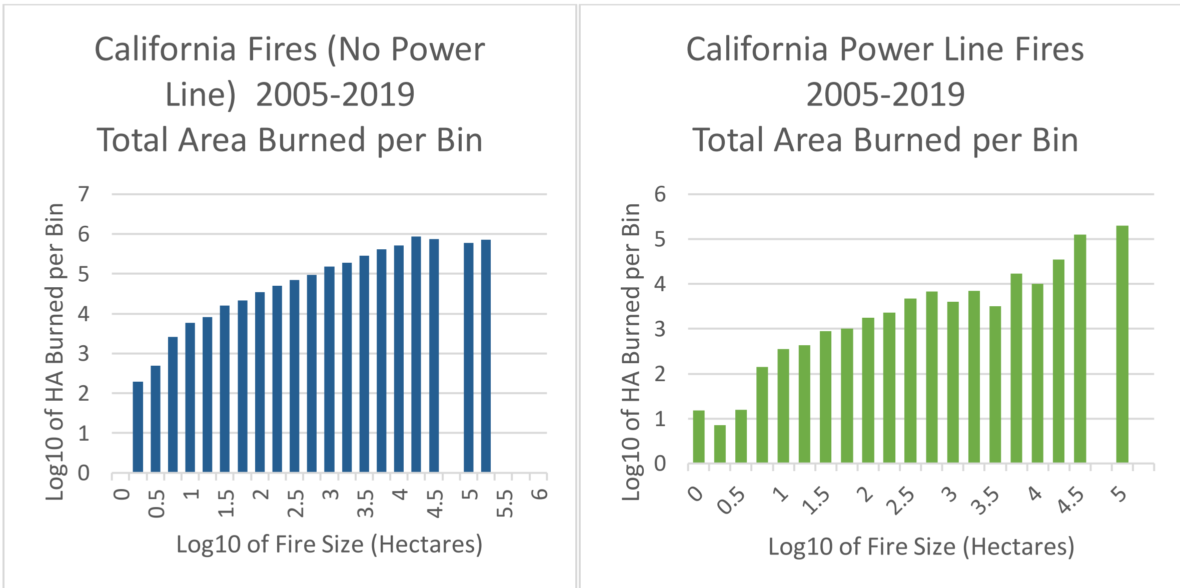

Figure 5 - Total area burned per logarithmic bin for California wildfires 2005 to 2019, calculated by multiplying logarithmic mean of bin by number of wildfires in the bin. Power line related wildfires are compared against full sample with wildfires removed. It is important to note that these are not cumulative plots.

The results of this formulation are a striking demonstration of the implications of power law statistics. It should be emphasized that the vertical axis of these plots is logarithmic. They show that the vast majority of loss potential comes from the most extreme events. For the wildfire sample with power line attribution removed, a plateau is observed at a value of 4 on the horizontal axis (30,000 acres). Losses at or above this level combined exceed all contributions from smaller wildfires. For power line fires the effect is even more dramatic. The two highest contributing bins (above 90,000 acres) contributed more acres burned than all smaller power line wildfires combined. As I observed in a 2004 wildland firefighter trade magazine article, "***the catastrophic is typical***".[16] Typical events are small. Typical losses are from catastrophic events.

These plots also demonstrate the amplified, even dominant, effect of uncertainty. The fact that there are empty bins for larger fires indicates that the contribution of extreme value fires is

[16] https://www.mbartek.com/weeds-info/5-wildfire-magazine-article
JosephW. Mitchell; WEEDS: Firebrand Defense for the "Typical Catastrophe"; Brand Dilution (Cover article); Wildfire Magazine; Mar. 2005.

strongly affected by statistical fluctuations. ***The largest contributions come from the portion of the distribution with highest uncertainty.*** Likewise, while we expect that there is a cutoff in the power law behavior, the exact point of cutoff is not well known, but the value of this cutoff will have dramatic effects on the results of risk calculations. Consequently, any risk calculation based on our knowledge of wildfire statistics needs to be accompanied by a great deal of humility – there is a significant likelihood that estimates can be off by quite a lot.

While the methodology proposed in this paper will be robust against these uncertainties, risk estimates used to set thresholds will still be subject to these effects, and should always be checked against model assumptions.

2.6. Utility Wildfire Ignition Probability Dramatically Increases During Extreme Weather Events

The other side of the utility wildfire risk equation is frequency of ignitions. While some ignitions occur throughout the year in response to various drivers, period of extreme stress due to wind can cause dramatically increased outage rates due to wind damage and vegetation contact. Along with this damage, if the winds occur during periods of low relative humidity and dry vegetation, energy released from the fault is quite likely to ignite a wildfire.

The extreme dependence of outage rates on local wind speeds was shown Mitchell 2012.[17] This work studied SDG&E outage data and measured the relative probability of outages on circuits based on the peak wind gust speed at the nearest weather station.

[17] Mitchell, J.W., 2013. Power line failures and catastrophic wildfires under extreme weather conditions. Engineering Failure Analysis, Special issue on ICEFA V- Part 1 35, 726–735. https://doi.org/10.1016/j.engfailanal.2013.07.006

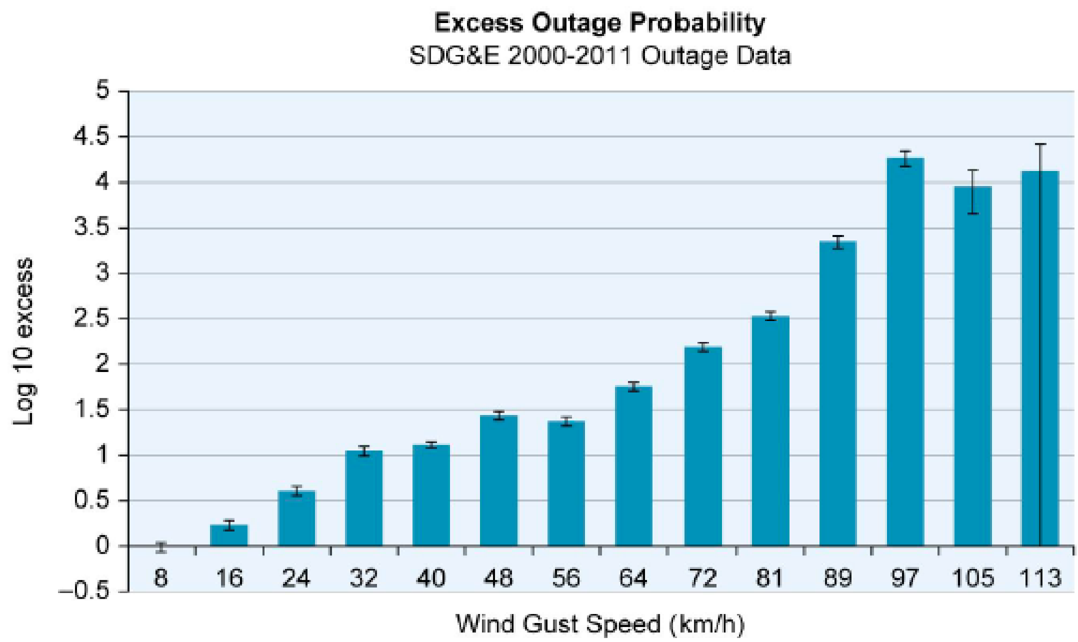

Figure 6 - Excess outage probability as a function of wind speed obtained by normalizing SDG&E outage data with historical Mesowest weather station data. For each outage, a wind speed was determined at the nearest appropriate weather station for the circuit having the outage. Historical data for each of these weather stations was analyzed to determine what fraction of time the wind speed exceeded the speed at which the outage occurred. Data were then normalized against a baseline wind speed of 8 km/hr, giving the number of outages per unit time at a particular wind speed at that location compared to number of outages that would be expected during calm weather. The vertical scale is logarithmic. Data show a ten-fold increase in outage rate for every 15-20 mph increase in wind gust speed. Reproduced from Mitchell 2012, Footnote 17.

Syphard and Keeley 2015 analyzed fires in San Diego County and the Santa Monica Mountains, and found that powerline-related fires, moreso than any other fire ignition type, were correlated with the "southwestness" of the ignition point. In other words, infrastructure that ignited had more exposure to northeasterly Santa Ana winds.[18]

Other studies have verified that power line fires are more frequent during fire weather and cause greater damage, such as Miller et. al., who verified this effect in Australia.[19]

[18] Keeley, J.E., Syphard, A.D., 2018. Historical patterns of wildfire ignition sources in California ecosystems. Int. J. Wildland Fire 27, 781–799. https://doi.org/10.1071/WF18026 https://www.academia.edu/download/41195924/54d3a7b00cf2b0c6146deaae.pdf20160115-19908-1ft4a7s.pdf
[19] Miller, C., Plucinski, M., Sullivan, A., Stephenson, A., Huston, C., Charman, K., Prakash, M., Dunstall, S., 2017. Electrically caused wildfires in Victoria, Australia are over-represented when fire danger is elevated. Landscape and Urban Planning 167, 267–274. https://doi.org/10.1016/j.landurbplan.2017.06.016

2.7. Summary and Implications of Power Line Wildfire Characteristics

Wildfires sparked by electric utilities tend to be larger and more destructive because external drivers such as high winds significantly increase the frequency of ignitions, and the very same drivers are a component of extreme fire weather, which causes rapid growth of wildfires and is linked to greater wildfire sizes and impacts. The statistical distribution of power line wildfires has consequences for risk estimation.

The power law exponent for power line wildfires is small, less than 0.5. This throws a monkey wrench into standard statistical treatments, which are based on projections from historical data. What an exponent this small implies is that one cannot derive an accurate mean using past history. Future events will always be larger, and throw off any mean based on backwards-looking data. This is true for any exponent less than 1.0. As Taleb writes about this type of power law, "…there is no mean. We call it the Fuhgetaboudit. If you see something in that category, you go home and you don't talk about it."[20] Those of us who have homes in the wildland urban interface do not have the luxury of fuhgettingaboudit. If we ever do, we will be reminded sooner or later by the smoke and red glow over the next hill. Fortunately, we have better options, for two reasons.

- As noted by several authors and shown in the most recent California power line fire statistics, there should be a cutoff at a maximum scale. This should allow a statistical treatment.
- Even though uncertainties in the cutoff value could have dramatic effects, we can avoid this problem by placing extreme events into a class handled by a heuristic approach.

The "heuristic approach" discussed in this paper is power shutoff, and it is already in practice, but is currently not quantitatively balanced against other risks. The framework laid out in this paper is designed to incorporate the extreme event statistics into the MAVF framework and lay out how both harm and benefit from "PSPS" can be balanced to optimize utility mitigation spending for the public benefit.

[20] Taleb, N.N., 2020. Statistical Consequences of Fat Tails: Real World Preasymptotics, Epistemology, and Applications. STEM Academic Press. https://arxiv.org/abs/2001.10488; pp. 27-28.

3. PROPOSED MECHANISM TO COUPLE WILDFIRE RISK TO DRIVER EVENTS

As should be evident, the utility wildfire problem is complex, and finding a mechanism to address it correctly is difficult, particularly within the MAVF framework. The following proposal makes a number of simplifications and assumptions, but should nevertheless capture the most important characteristic of power line wildfire risk while still making use of the existing MAVF framework. The outline for this proposal is:

- Determine the maximum scale cutoff for wildfire events.
- Create a library of historical fire weather events classified in order of fire weather severity, and specifying extent and duration.
- Separate out "baseline" and "weather-driven" ignition risks into two tranches.
- Subdivide weather driven ignition risks into weather severity tranches.
- For each weather severity tranche,
  - determine a power law slope, and corresponding mean consequence,
  - determine a PSPS impact multiplier (geographic area X time), and from this a corresponding PSPS risk,
  - determine a characteristic wind speed, and from this,
    - a risk event frequency multiplier, and
    - specific mitigation effectiveness for each mitigation (such as hardening)

The MAVF should not have a cap in consequences to ensure that extreme events have an adequate contribution, and ideally should be a linear function.

The advantages of this approach are:

- It is consistent with the MAVF model.
- It allows the incorporation of new climate data as it becomes available.
- It allows PSPS harm to be directly compared to averted wildfire costs.

- It allows the specification and optimization of PSPS thresholds and mitigations in terms of weather severity. The goal of mitigations would be to replace PSPS within a specific weather severity tranche.

3.1. Maximum Scale for Wildfire Sizes

To the extent that wildfire sizes follow a power law, trying to define a maximum scale is a fool's errand. However, trees do not grow to the sky, and wildfires do not burn into the sea. There is a maximum size that a fire can reach before it encounters non-flammable area, devoid of vegetation, or composed of fire-resistant human developments. These limitations will cause deviations from power law behavior.

As Moritz, et. al. 2005 notes: "A large size cutoff…. should therefore be fit to the cumulative distribution to reflect the maximum fire sizes, resulting in a truncated model that captures changes in the large event tails and avoids artifacts of bin width selection in the noncumulative probability density. Without this specification, relatively large errors will occur in predicting large event probabilities."[21]

The fact that we don't have definitive evidence for these limits in California wildfire data should be a matter for grave consideration and concern. We should expect to continue to have record-breaking wildfires. Exactly what this scale is should be based on should be a matter for expert review, but an approach similar to that of Clauset, Shalizi, and Newman[22] but incorporating fire size data from 2012-2020 should be undertaken. Whether to use a cutoff similar to the HOT model or the exponential cutoff suggested by Clauset, Shalizi, and Newman should be looked at as well.

3.2. Identify and Classify Historical Fire Weather Events

Identifying and classifying fire weather events independent of wildfire ignitions is important for risk analysis for several reasons:

- Multiple wildfires are often ignited during the same severe weather event.

[21] See Footnote 9.
[22] Clauset 2009.

- The extent and duration of utility de-energization (and associated customer harm) will be a function of weather event severity.
- Determining the distribution and severity of wildfire weather events will allow climate models to be incorporated into the risk calculations in a straightforward way.

For example, a severe fire weather event might cause an extended power shutoff over a widespread area. Even if this event does not result in any major wildfires or utility ignitions, it still should be characterized as a risk event in the MAVF framework because it does harm.

The metric used to determine event extremity could be a standard fire weather severity index, such as Fosberg Fire Weather Index, utility-determined Fire Potential Index (FPI), Santa Ana Weather Threat Index (SAWTI), or a wind-dependent metric. Studies such as Abatzoglou, et.al. (Footnote 13) have performed this kind of analysis, so it should be straightforward to select and incorporate an appropriate model that will allow us to classify past fire weather event severities and extents.

3.3. Baseline and Weather-Driven Wildfire Events

To some extent all wildfires have weather-dependent characteristics, since they presuppose the existence of dry vegetation. However, utility wildfires should be subdivided into weather-driven and baseline tranches because certain drivers are weather-related and others are not. Wildfire ignition drivers such as animal contact, vehicle collisions, and human error have no relationship to weather, whereas others such as equipment damage and vegetation contact may or may not be weather related. Creating a “baseline” tranche allows utilities to use a Poisson distribution to model the frequency, since the probability of a risk event is constant over time, and the consequence can be modelled by a power law with cutoff that is characteristic of low-wind events.

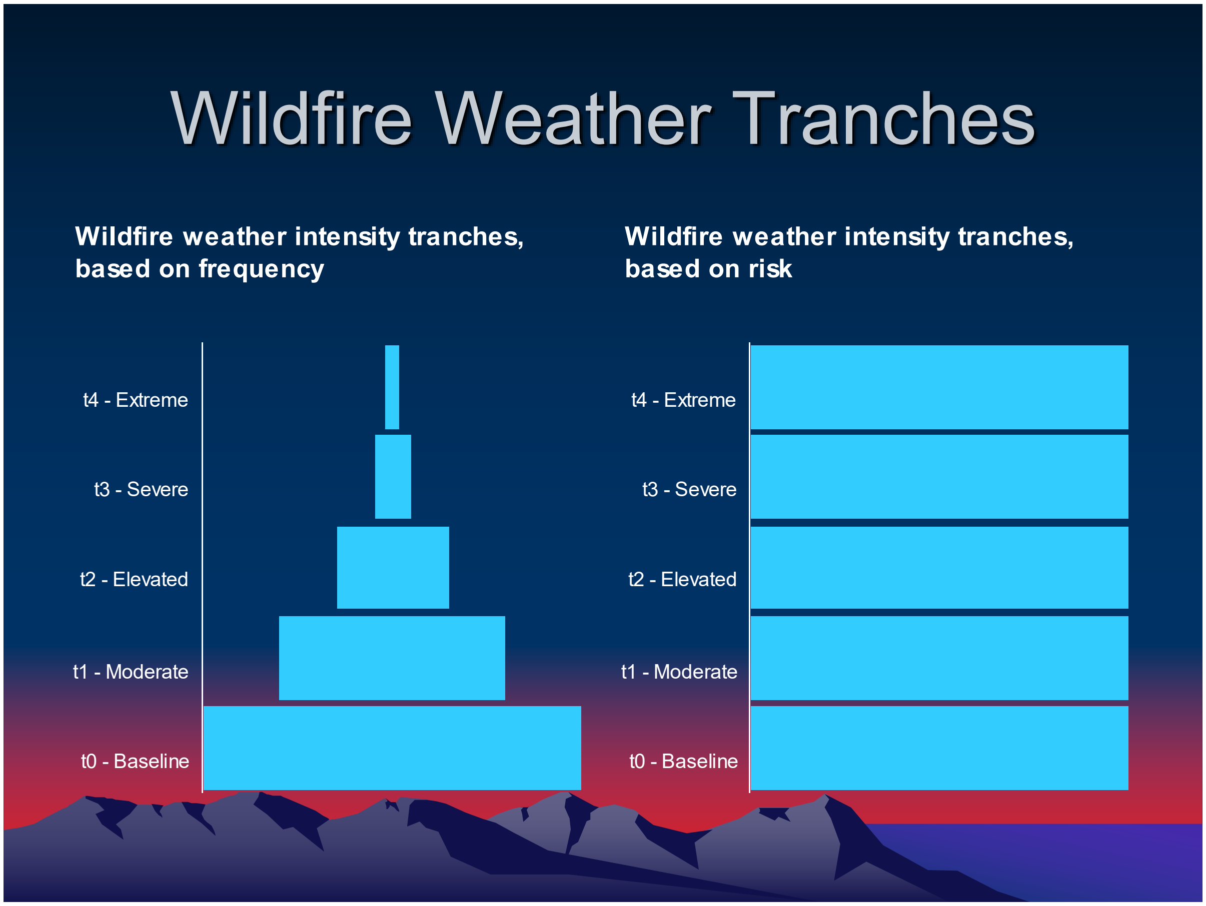

Figure 7 - Division of wildfire data into fire weather severity tranches. Tranches representing higher severity fire weather will be less frequent, but tranches should have equivalent risk because the wildfire consequences will be higher during more extreme weather events.

3.4. Weather-Driven Event Tranches

The remainder of wildfire events should be divided into tranches related to weather severity. The number of tranches should cover the range from moderate (but still above baseline) to extreme.

The Settlement Agreement foresees that tranches should be roughly equivalent in contributed risk.

3.4.1. Fire weather event frequency

Once the definition of the fire weather metric used to classify events has been identified, it can be determined how frequently events of each class occur. Because a large contribution from rare, extreme events is expected, the overall frequency for higher weather severity tranches will be expected to be much lower than those of lower weather severity tranches.

To examine fire weather history, the entire dataset of California wildfire data should be used to the extent that it is possible to construct an accurate history of the fire weather severity metric.

3.4.2. Fire weather severity tranche impacts.

Consequences from a fire weather severity tranche can be estimated from the wildfire size distribution of historical wildfires in that tranche. Essentially what is needed is an equivalent of the work done by Boer, et. al.[23] for Australia, except for California fires. It should be expected that each of these tranches of increasing fire weather severity would have an exponent that decreases correspondingly.

An example of how this might qualitatively look is shown in below.

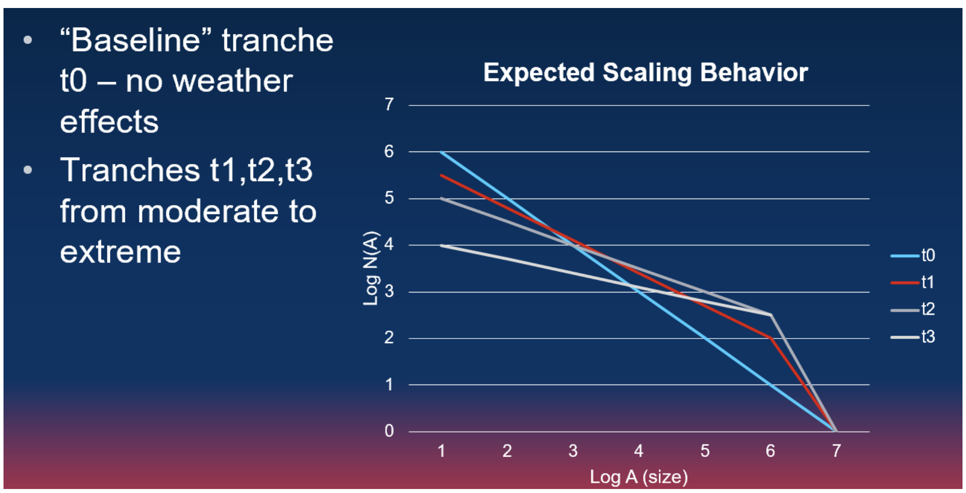

Figure 8 - Hypothesized scaling behavior for fire weather severity tranches t0, t1, t2, t3 of increasing wildfire severity. Expected behavior is power law with cutoff. Lesser slope (smaller exponent) is expected as wildfire weather event severity increases. The largest fires are expected to generally be during the most severe weather, as per Boer, et. al. Slope differences are amplified to demonstrate this effect. This plot assumes a common cutoff for all weather conditions, but it is likely that maximum possible wildfire size will be lesser for less extreme weather severity.

In Figure 8, we assume that there is a common cutoff size for all weather tranches, equivalent to the maximum size of a fire that the landscape can support. Data should be examined, however, to ascertain whether there is a lower cutoff for the baseline tranche or less severe fire weather.

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[23] Boer, et. al.; Footnote 12.

It may also be possible to use wind speed as a differentiator between tranches. There will be a relationship between fire weather severity and wind speed. Mitchell 2009 plots fire sizes versus maximum gust speed at nearest weather station, with relative humidity less than 20%.

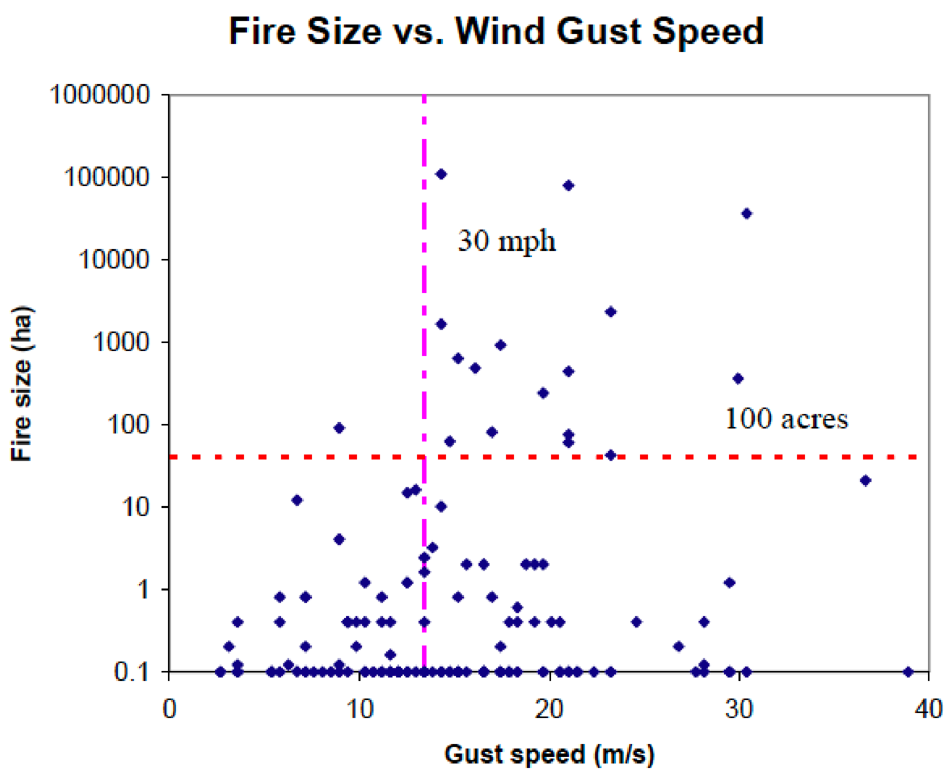

Figure 9 - Reproduced from Mitchell 2009. This plot shows fire sizes as a function of wind gust speed at the nearest weather station within 12 hours.

Based on more recent research by Coen, et. al., using the single nearest weather station is not likely to provide an accurate wind speed result at the point of ignition.[24] An upcoming paper by Prein et. al. will classify fire weather into "Extreme Weather Types" (XWT),[25] and determine frequencies for the occurrence of these XWTs. A similar effort, with a metric for intensity of the weather event could be used as a tranche designator.

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[24] Coen, J.L., Schroeder, W., Conway, S., Tarnay, L., 2020. Computational modeling of extreme wildland fire events: A synthesis of scientific understanding with applications to forecasting, land management, and firefighter safety. Journal of Computational Science 45, 101152. https://doi.org/10.1016/j.jocs.2020.101152
[25] Prein, A., J. Coen, A. Jaye, 2021: The Character and Changing Frequency in Extreme California Fire Weather. Nature Climate Change. Submitted.

To summarize: the goal of the division of wildfire data into tranches is to determine a frequency and consequence for each tranche, and to provide a distribution for each tranche that can be used in a later Monte Carlo analysis. Once this is obtained it can then be used to assess power line wildfire risks.

3.5. Determining a power line ignition frequency multiplier

Each fire weather severity tranche will be associated with elevated wind levels, and these will in turn be associated with higher outage rates and power line fire ignition rates. The next step in the analysis is to determine the power line ignition frequency multiplier for each tranche. This multiplier measures how much more likely a power line fire is to occur in the elevated tranche than it is during the baseline tranche. There are several possible ways to obtain this number:

- A straightforward way to obtain a multiplier is to compare the relative fraction of power line initiated wildfires to the total number of wildfires in each tranche, using CAL FIRE data.
- Utility ignition data can also be analyzed after ensuring that all contested major events are included. Fire weather severity would need to be estimated for each ignition point. This method is not accurate for data after 2018, when power shutoff-became a common practice. Furthermore, ignition data was not collected by PG&E or SCE prior to 2016, leaving a very limited set of data to extrapolate from.
- Utility outage or ignition data can also be used to estimate the frequency multiplier. As an intermediate step, a typical wind gust speed would need to be estimated for each tranche. Outage data can be analyzed to find a multiplier associated with that particular wind speed, such as done in Figure 6. An ignition fraction would need to also be determined for outages. The advantage to using outages is that there are abundant statistics to capture more extreme wind events, and also sensitivity to wind outside of fire danger periods is captured.
- A supplemental metric that could help to supplement ignition data are damage incidents reported by utilities for each de-energization event.

It might be beneficial to cross check these techniques against each other to validate the frequency multiplier.

3.6. PSPS Risk

The previous section laid out how to estimate the risk of wildfire ignition in different fire weather severity tranches. In order to construct a complete risk profile it is necessary to take into account de-energization not only as a mitigation but as a source of risk, and also to predict how these risks will scale as a function of fire weather severity.

Many different potential PSPS risks have been highlighted by stakeholders and intervenors over the years. One list provided by MGRA in R.18-12-005 is illustrative:

- *Risk of loss of communication*
  - *Risk that fires are not reported*
  - *Risk that people are not informed regarding approaching fires*
- *Risk of improper resident mitigations causing house fires that turn into interface fires*
  - *Risk of candle ignited fires*
  - *Risk of improperly maintained generators causing fires*
  - *Risk of barbeque or fire-pit ignited fires*
  - *Risk that a house fire in a WUI area progresses to an interface fire*
- *Delays in evacuation putting residents at risk*
  - *Nighttime evacuation hampered by lack of home power*
  - *Failure of traffic signals causing traffic backups*
- *Danger to vulnerable residents*
  - *Medical baseline customers requiring power*
  - *Financial harm to marginal residents living paycheck to paycheck*[26]

As California gains more experience from power shutoff events, some of these risks which were hypothetical when proposed are now being observed, anecdotally at least. For instance, the Tick fire, in SCE territory, was alleged to have been started as a cooking fire, while the Thief fire has been alleged to have been a generator fire.

[26] R.18-12-005; MUSSEY GRADE ROAD ALLIANCE PHASE 2 TRACK 1 DE-ENERGIZATION PROPOSALS; September 16, 2019; p. 3.

Coupled to the risk of de-energizing is the risk of *not* de-energizing, or de-energizing in the wrong places or at the wrong times. A number of wildfires have been reported that occurred proximate to PSPS events, geographically or in time, in areas that were not de-energized:

Fire	Date	Utility
Camp	November 8, 2018	PG&E
Kincade	October 23, 2019	PG&E
Zogg	September 27, 2020	PG&E
Silverado	October 26, 2020	SCE
Cornell	December 7, 2020	SCE

Table 1 – Wildfires with alleged utility involvement that were started near PSPS events geographically and in time.

This S-MAP proceeding will deal with quantification of PSPS risks as a separate issue. How to incorporate PSPS risks (and benefits) into a MAVF framework, though, is critical for a complete characterization of electrical utility risk, and so we include an outline of how to incorporate PSPS risks and benefits into this proposal.

3.6.1. PSPS Impact Multiplier

More severe fire weather events have generally resulted in longer and more geographically widespread PSPS events. The relationship between fire weather severity and PSPS impacts needs to be quantified for each fire weather severity tranche. The harm and cost from PSPS events will approximately scale with the number of people and businesses affected. Efforts to determine PSPS costs/harm should result in a per/person-hour quantity. This would be used in conjunction with the impact multiplier to provide a PSPS risk distribution (and mean value) per tranche.

The base risk from PSPS should be determined by a dedicated effort by utilities and stakeholders and led by the Commission or WSD. Previous PSPS experience and domain expertise in conjunction with weather data can be used to estimate the fire weather severity multiplier.

There will be no PSPS risk for the baseline tranche, and for no tranches of greater fire weather severity that have been "cleared" for safe operation.

3.6.2. PSPS-Related Ignitions, PSPS Inefficiencies, and Increased Consequences

Some PSPS-related risks will scale with factors other than just the extent and duration of a a shutoff event. For instance, the consequences of PSPS-related wildfire ignitions (cooking, candles, generators, delayed reporting) would be expected to scale with the fire weather severity.

Likewise, fires ignited due to the failure to de-energize a circuit that was operating beyond its maximum safe level of fire weather severity would also potentially contribute to a fire ignition rate.

Both of these risks would be handled in the same way in the MAVF: The wildfire risk in a tranche protected by PSPS would not be zero but instead be a small residual value that also scales with the PSPS impact multiplier. These residual risks – for both PSPS-related ignitions and PSPS inefficiencies, should be calculated from what we've learned from PSPS experience in the two years it has been operational statewide, in conjunction with domain expert input and larger ignition datasets from outside of California.

De-energization will also increase risks for people in the path of a wildfire that is not related to PSPS or to utility ignition. It will make it more difficult to evacuate, especially for the elderly or people with special needs. It will also hamper communication. This risk is harder to quantify. It would affect the consequences of external wildfires, and would not have a frequency component. For simplicity's sake, it could also be treated in the same manner as PSPS inefficiencies. It will need to be estimated with input from stakeholders and subject matter experts, and informed by anecdotal PSPS data, as part of a Commission effort to quantify PSPS harm.

3.7. Optimized Mitigation with a Heuristic Kill-Switch

The form of wildfire mitigation that has evolved since D.09-09-030 (and ESRB-8 thereafter) consists of general hardening of utility infrastructure against ignition events (including increased vegetation management), with the option to shut off power if there is a present danger of equipment damage. To date this has mostly been a decentralized process left to the prioritization of IOU transmission and distribution groups. So far, there have been no utility hardening goals specifically targeted to safe operation above a certain threshold, at least insofar as appearing in CPUC proceedings. The goal of this paper is to lay out a simple conceptual framework using fire weather severity tranches to identify specific target levels for mitigation. This can be thought of as optimized mitigation with a heuristic kill switch. Standard cost/benefit or RSE techniques can be used to optimize mitigations to "clear" lower fire weather severity tranches for safe operation. Fire weather severity above a certain tranche level triggers the "kill switch", or PSPS. Like a circuit breaker, PSPS helps to protect against extreme tail event risks. It essentially trades a known (and very substantial) harm against a rare but possibly catastrophic potential harm.

The purpose of mitigation is to reduce risk, either by reducing the frequency or reducing the consequences of the risk events. This can take three forms in the current model:

1. Mitigation to reduce wildfire risk. This should be estimated per tranche, since effectiveness of a mitigation may vary with fire weather severity. Undergrounding, for instance, would be effective in all tranches. Hardening of a certain type may only be good up to a corresponding wind speed – hence the effectiveness would be lower in the higher tranches.
2. Mitigation to reduce PSPS impacts. Specific mitigations will reduce PSPS impacts by a certain fraction. The effectiveness of this mitigation would be expected to be independent of fire weather severity.
3. Mitigation to reduce the frequency of PSPS events by making the system safe to operate in a higher fire weather severity tranche. Hardening a circuit so that it can operate under conditions of "moderate" fire weather severity would be an example of this kind of mitigation. This class of mitigation reduces both wildfire risk and PSPS risk.

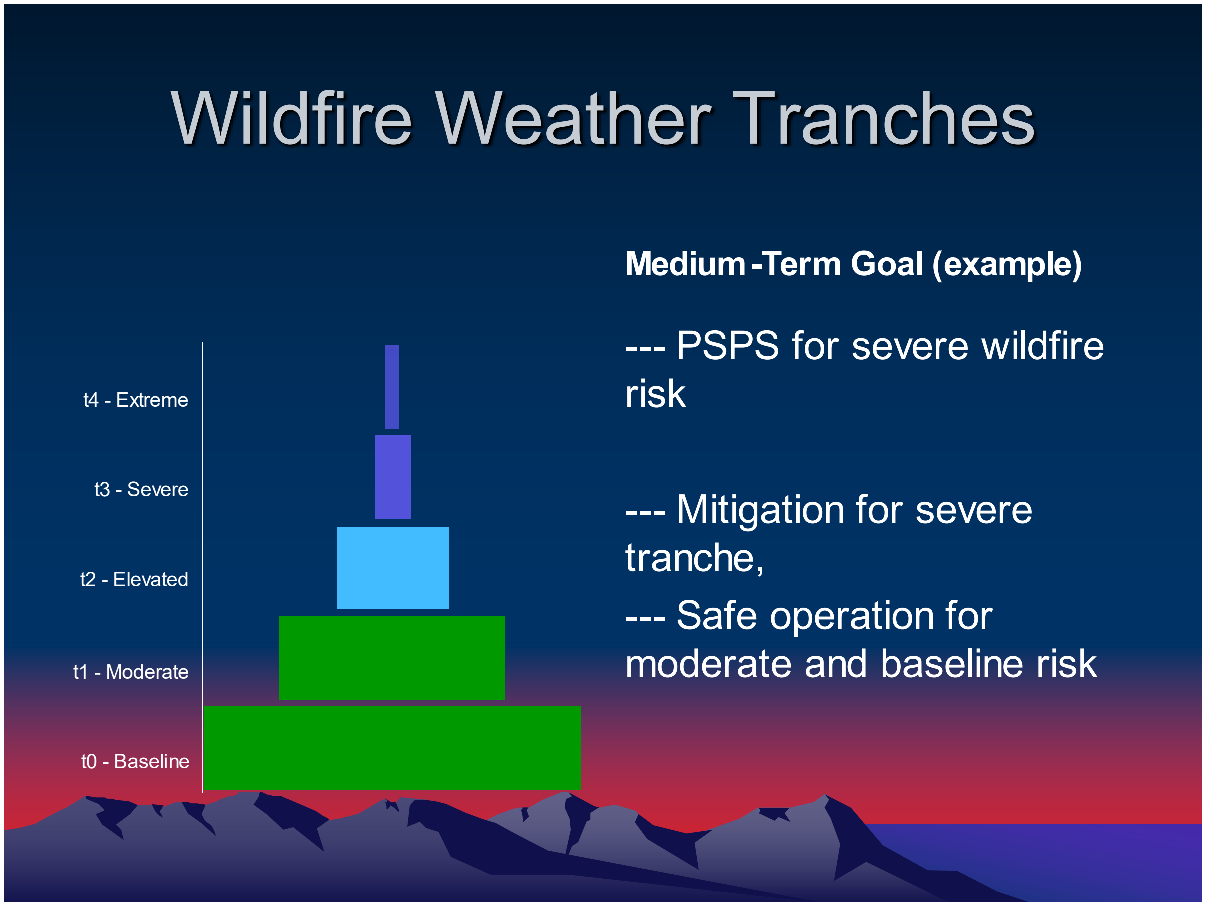

Figure 10 - Example of a risk analysis for a utility that is able to operate safely under moderate fire weather conditions. It evaluates and undertakes mitigations that would let it operate under elevated fire weather conditions. PSPS remains a last resort for severe and extreme fire weather conditions.

Different mitigations, therefore, are targeted to different fire weather severity tranches, and as a utility's wildfire prevention program matures its goal should be to operate safely under conditions of greater and greater fire weather severity. In the long run, there may be technical breakthroughs (such as the combination of REFCL and covered conductor) that would allow safe operation under all foreseeable weather conditions. Until and unless such solutions are deployed, however, de-energization remains a last resort option for the most extreme events. How robust utility systems must be to fire weather can be determined by a cost benefit analysis via the risk-spend efficiency of the MAVF.

3.8. Assembling the MAVF

This section proposes an approach to assembling a multi-attribute value function that incorporates power law dependencies, weather severity tranches, risks from both wildfire and power shutoff, and mitigations.

3.8.1. Components of the MAVF

Tranches: $t_i \ldots t_N$

There are N fire weather severity tranches, each designated by t_i.

Baseline Tranche: t_0

The baseline tranche contains all risk events that do not occur during times of fire weather.

Baseline Wildfire Rate: F_0

The wildfire fire frequency in the baseline tranche.

Fire Weather Event Frequency: f_i

The fire weather event frequency is the number of weather events of tranche *i* occurring annually.

Fire Multiplier: π_i

The fire multiplier is the mean increase in the number of significant wildfires in tranche *i* over the baseline wildfire rate. This will lead to a number of fires per risk event.

Note: The problem of fire complexes, in which wildfires merge, or wildfires with several contributing ignitions (i.e. Tubbs) will need to be addressed so as not to cause double counting of fire starts.

Tranche Wind Speed: v_i

The typical maximum wind speeds during a wildfire weather event in tranche *i*. This may be used to obtain a power line fire frequency multiplier from outage rates. It may also be used for engineering requirements for mitigations in tranche *i*.

Power Line Frequency Multiplier: P_i

The power line frequency multiplier characterizes how much the probability of a wildfire ignition event is increased in fire weather severity tranche *i*. As discussed above, it can be derived from 1) observed ratio of recorded power line fires per tranche 2) increase in ignition frequency from utility data as a function of weather severity tranche or wind speed 3) increase in outage rate as a function of wind speed.

Wildfire Consequence Distribution: dW_i/dA_i
Wildfire Consequence Mean: $\overline{W}_i$
Cutoff Size: A_{max}
Minimum Reliable Size: A_{min}
Power Law Exponent: α_i

The wildfire consequence distribution in a tranche is the cumulative number of wildfires above a certain area, plotted as a function of area. This value can also be weighted with a value quantifying mean customer harm per unit size of the wildfire. Alternatively, the size can be dispensed with and a plot of wildfire costs can be used, but this would take considerably more work because the problem has not been approached this way before.

A mean of the distribution may also be used, obtained by

$$\overline{W} = \int_{Amin}^{Amax} \frac{dW(A)}{d(A)}\, dA$$

It is recommended, however, to use Monte Carlo methods instead because the distribution, characterized by a power law over several orders of magnitude, and therefore the probability of outlier events of much greater consequence in any given weather tranche is significant.

The distribution will be characterized by a power law. An example function that can be used to fit the form to enable a parameterized Monte Carlo is the HOT/PLR formulation of Moritz, et. al.:

$$dW_i(A)/dA = C[(A_{min} + A)^{-\alpha_i} - (A_{min} + A_{max})^{-\alpha_i}]$$

De-energization Severity: d_i, $i > 0$

De-energization Consequences: $D_i = Sd_i$

The severity of de-energization is a value that expresses the extent of a shutoff event (possibly in customer-hours). This can be multiplied by a consequence multiplier S to create a consequence value D_i in units equivalent to the attribute (safety, financial, reliability). Each fire weather severity bin which uses PSPS as a mitigation will have a characteristic de-energization severity.

De-energization Inefficiency: ε

Even when lines are de-energized, there is a residual component of fire risk. This has three subcomponents:

- Utility-related ignition due to inefficiency and error in estimating the correct PSPS boundaries and timing.
- Increased fire risk from sources related to PSPS, such as cooking, generators, and delays in reporting.
- Increased risk to residents from wildfires that are not related to PSPS due lack of communication, traffic signaling, and inefficiencies from evacuating in the dark.

These could be individually addressed but for simplicity these are combined into a single parameter ε. Residual wildfire risk will be the inefficiency parameter multiplied by the wildfire risk and PSPS severity.

Wildfire Mitigation Efficiency: w_i^j

De-energization Mitigation Efficiency: q_i^j

MAVF allows the incorporation of mitigation measures. If there are W uncorrelated wildfire mitigation measures, then the residual wildfire risk for a specific fire weather severity tranche would be

$$r_i = \prod_{j=1}^{W} (1 - w_i^j) R_i$$

where R_i is the unmitigated risk in tranche *i.*

3.8.2. Wildfire risk calculation in the baseline tranche

The baseline risk due to wildfire ignition will take the following form:

$$\boldsymbol{R_0 = F_0 P_0 \overline{W}_0}$$

This is the simplest formulation, and represents the ambient risk of power line wildfire ignition in the absence of weather drivers. As a Monte Carlo, it can be represented as a Poisson distribution of events with consequences drawn from the wildfire consequence distribution $\mathbf{d}\boldsymbol{W_0}/\mathbf{dA_0}$, which can be represented by a power law with minimum and maximum cutoffs A_{min} and A_{max} and exponent α_0.

3.8.3. Wildfire risk calculation in tranches without PSPS

For tranches associated with fire weather events, the formulation takes into account the both the frequency and the amplification effects of these events.

$$\boldsymbol{R_i = f_i \pi_i P_i \overline{W}_i}$$

This includes a multiplier, $\boldsymbol{\pi_i}$, that represents how many fires, on average, occur during a fire weather event in severity tranche *i*. As a Monte Carlo, the weather event would be treated as a Poisson distribution, as would the number of fires generated from the event. The consequence distribution would be drawn from $\mathbf{d}\boldsymbol{W_i}/\mathbf{dA_i}$, which can be represented by a power law with minimum and maximum cutoffs A_{min} and A_{max} and exponent α_i.

3.8.4. PSPS and wildfire risk calculation in tranches with PSPS

In the case where PSPS is used to mitigate wildfire risk in a fire weather severity tranche, the risk from PSPS can be given as

$$\boldsymbol{R_i^{PSPS} = f_i D_i}$$

where P_i are the PSPS consequences calculated for a fire weather event in fire weather severity tranche *i*.

There are also potential inefficiencies in PSPS, as described above. These leave residual wildfire risks associated with weather severity tranche *i*.

$$\boldsymbol{R_i^{WF} = f_i \pi_i \varepsilon_i P_i \overline{W}_i}$$

The total tranche PSPS risk is the combination of the PSPS harm and residual wildfire risk.

$$\boldsymbol{R_i = R_i^{PSPS} + R_i^{WF} = f_i(D_i + \pi_i \varepsilon_i P_i \overline{W}_i)}$$

3.8.5. Wildfire risk vs. PSPS

The decision whether to apply PSPS as mitigation to a fire weather severity tranche or to leave it energized during an event of that severity then comes down to the following relation:

If this wildfire risk > PSPS risk, de-energize in the event of a weather event.

De-energization criterion for fire weather severity tranch *i*:

$$\boldsymbol{\pi_i \overline{W}_i > D_i + \pi_i \varepsilon_i P_i \overline{W}_i}$$

or

$$\boldsymbol{\pi_i (1 - \varepsilon_i) P_i \overline{W}_i > D_i}$$

The meaning of this criterion is that: "In order to shut off power, risk from wildfire needs to be greater than the risk from de-energization, including any wildfire risks that are caused or increased by PSPS".

Mitigations can be applied to both reduce wildfire risk and PSPS risk.

As shown in Section 3.8.1 the residual wildfire risk for a specific fire weather severity tranche is

$$r_i = \prod_{j=1}^{W} (1 - w_i^j) R_i$$

where R_i is the unmitigated risk in tranche i and a series of wildfire mitigations with efficiency w_i^j are applied. The equivalent value for PSPS mitigations would be:

$$r = \prod_{j=1}^{Q} (1 - q^j) R_i$$

In this case, PSPS mitigations, such as generators or microgrids, will have an effectiveness that is independent of fire weather severity, so there is no i tranche subscript.

Say that a utility sets a goal of upgrading a subset of its infrastructure so that it can safely operate under fire weather severity tranche t_2. It proposes a portfolio of W wildfire mitigations and Q PSPS mitigations. In order for it to meet the criteria for safe operation, it would need to meet the criterion:

$$\prod_{j=1}^{W} (1 - w_2^j)(1 - \varepsilon_2)\pi_2 P_2 \overline{W}_2 < \prod_{j=1}^{Q} (1 - q^j) D_2$$

These mitigations would come at a certain cost, and would reduce risk by an amount:

$$R_2^{PSPS\,unmitigated} - R_2^{WF\,mitigated}$$

This allows a risk/spend efficiency to be calculated. This calculation is equivalent to the cost-benefit analysis for de-energization first foreseen in D.09-09-030.[27]

[27] p. 2.

4. OTHER CONSIDERATIONS

4.1. MAVF Attributes

The MAVF is a "multi-attribute" value function, and is designed to incorporate specified "values" into the risk function as separate entities. MAVF functions that have been used so far by utilities at the CPUC include attributes of "safety", "reliability", and "financial", each with certain weights. The wildfire risk, comprised both of harm from wildfires and harm from PSPS, has components of all of these attributes. This paper does not treat how the method above would be decomposed into safety (deaths, injuries, illness from smoke, PSPS safety risks), reliability (loss of customer power during PSPS), and financial (property destroyed). However the treatment should be similar to that already performed by IOUs in preparation of their RAMP risk analyses.

4.2. Other Tranches

IOUs, the Commission, and intervenors have suggested a number of other possible decompositions of risk into tranches. MGRA's position is that ideally tranches should be *actionable* – amenable to treatment by specific mitigations or providing specific risk information. The wildfire weather risk tranches meet this requirement, but other tranche definitions may be very useful as well. We recommend using fire weather severity tranches in combination with other valid tranches applicable to wildfire risk, which would multiply the number of overall tranches by the number of fire weather severity tranches.

4.3. Fitting with Other Distribution Types

A standard procedure used by both PG&E and SDG&E is to use a Monte Carlo based wildfire risk model based on utility ignition data and wildfire simulations. The wildfire losses are then fit with an extreme value distribution. In PG&E's case this is a lognormal and in SDG&E's case this is a gamma function. In both cases these are empirical fits to the data: they fit the data with reasonable accuracy, even though there is no fundamental theory underlying this fit.

Is this okay? The answer is "it depends".

The lognormal and exponential are classed as "subexponential" functions, which means that they do not have as extreme fat-tailed behavior as a power law.[28] A power law with tail exponent less than one (which is our lot) has the worst possible statistical behavior, in that its mean does not even converge in the limit of large numbers. The problem would not be tractable at all were it not for a maximum size scale for wildfires, which we believe to be there both from fire size distributions and from physical principles.

So the question comes down to how well do the candidate distributions fit real and generated data? Taleb 2020 notes that for some problems, differences between Pareto (power law) and lognormal distributions may be moot.[29] What is particularly important is that the fit be good well out onto the tails of the distributions, and also that the cutoff be handled in a realistic way. Due to the outsized contribution of events far out on the statistical tail, and the relative uncertainty regarding the frequency of these events, any errors or uncertainty in the tail up to the cutoff will dominate the overall uncertainty of the entire calculation. Under these conditions, it is likely that a power law with cutoff will give a better fit than alternative distributions.

IOUs who wish to use alternative fit functions should compare them against power law for efficacy and robustness against error, and should compare how they work on the extreme tails of existing data sets such as California wildfires (both without power line and with power line only).

4.4. Wind Speed versus Fire Weather Severity

One approximation made in this model is to associate a wind speed variable with each fire weather severity tranche. Because fire weather severity has a number of components (humidity, fuel moisture, temperature), a fire weather severity tranche will contain a range of wind speeds. Generally there will be a correlation between the two variables with higher weather severity tranches containing higher wind speeds. Power line faults are dependent on wind speed, and not the other variables, so by using weather severity as a tranche identifier we are likely underestimating power line ignition rates, though we would expect consequences to track more closely with fire weather severity rather than with wind speeds. Sensitivity of power line fire ignitions on wind can be estimated from the wind dependence of utility fault rates and from damage reports that utilities

[28] Taleb 2020; p. 89.
[29] Id.; p. 152.

provide in their post PSPS damage assessments. Use of ignition data itself is compromised after 2018 because of the use of PSPS, which suppresses ignition during extreme wind events.

Separating out these two effects would lead to greater accuracy and predictive capability. Ideally, a Monte Carlo treating these effects separately, with wind gust speed driving ignition frequency and fire severity driving consequences would likely lead to more accurate results.

4.5. Climate Change

One advantage of this approach is that it can readily incorporate input from climate models. Analysis of historical fire data indicate that the risk of wildfire is increasing throughout the Western United States in general and California in particular, and that this is due to anthropogenic climate change.[30,31] According to recent studies the climate variables driving the increase in fire risk appear to be related to higher temperatures and decreased humidity over a longer fire season.[32] Current climate models expect the intensity of Santa Ana winds to decrease over time, though this has not yet been observed in data.[33,34] This is surprising from a power line fire perspective, particularly with regard to Northern California. While power line fires have been known in Northern California, and have sometimes been catastrophic (for example, the Butte fire), the power line fire storm of 2017 followed the same pattern seen in Southern California in 2007, with near-simultaneous ignitions of multiple power line fires. The Camp fire followed in 2018, and had PG&E not implemented draconian power shutoff events, extensive damage to its infrastructure indicates that 2019 may have followed suite as a catastrophic fire loss year.

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[30] Williams, A.P., Abatzoglou, J.T., Gershunov, A., Guzman-Morales, J., Bishop, D.A., Balch, J.K., Lettenmaier, D.P., 2019. Observed Impacts of Anthropogenic Climate Change on Wildfire in California. Earth's Future 7, 892–910. https://doi.org/10.1029/2019EF001210 https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019EF001210

[31] Goss, M., Swain, D.L., Abatzoglou, J.T., Sarhadi, A., Kolden, C., Williams, A.P., Diffenbaugh, N.S., 2020. Climate change is increasing the risk of extreme autumn wildfire conditions across California. Environ. Res. Lett. https://doi.org/10.1088/1748-9326/ab83a7 http://iopscience.iop.org/10.1088/1748-9326/ab83a7

[32] Op. Cit.

[33] Hughes, M., Hall, A., 2010. Local and synoptic mechanisms causing Southern California's Santa Ana winds. Clim Dyn 34, 847–857. https://doi.org/10.1007/s00382-009-0650-4

[34] Guzman-Morales, J., Gershunov, A., 2019. Climate Change Suppresses Santa Ana Winds of Southern California and Sharpens Their Seasonality. Geophysical Research Letters 46, 2772–2780. https://doi.org/10.1029/2018GL080261

Whatever the cause of this sudden change in Northern California power line fire danger, it will be necessary to incorporate climate change into long term utility risk modelling. The model proposed in this paper can incorporate changes in annual fire rates and fire weather severity determined by climate models through the base weather event frequency F_0 and the weather severity dependent frequency multiplier f_i. Calculations of frequency in a high / extreme bin (fire weather index > 95%) can be found in Goss, et. al:

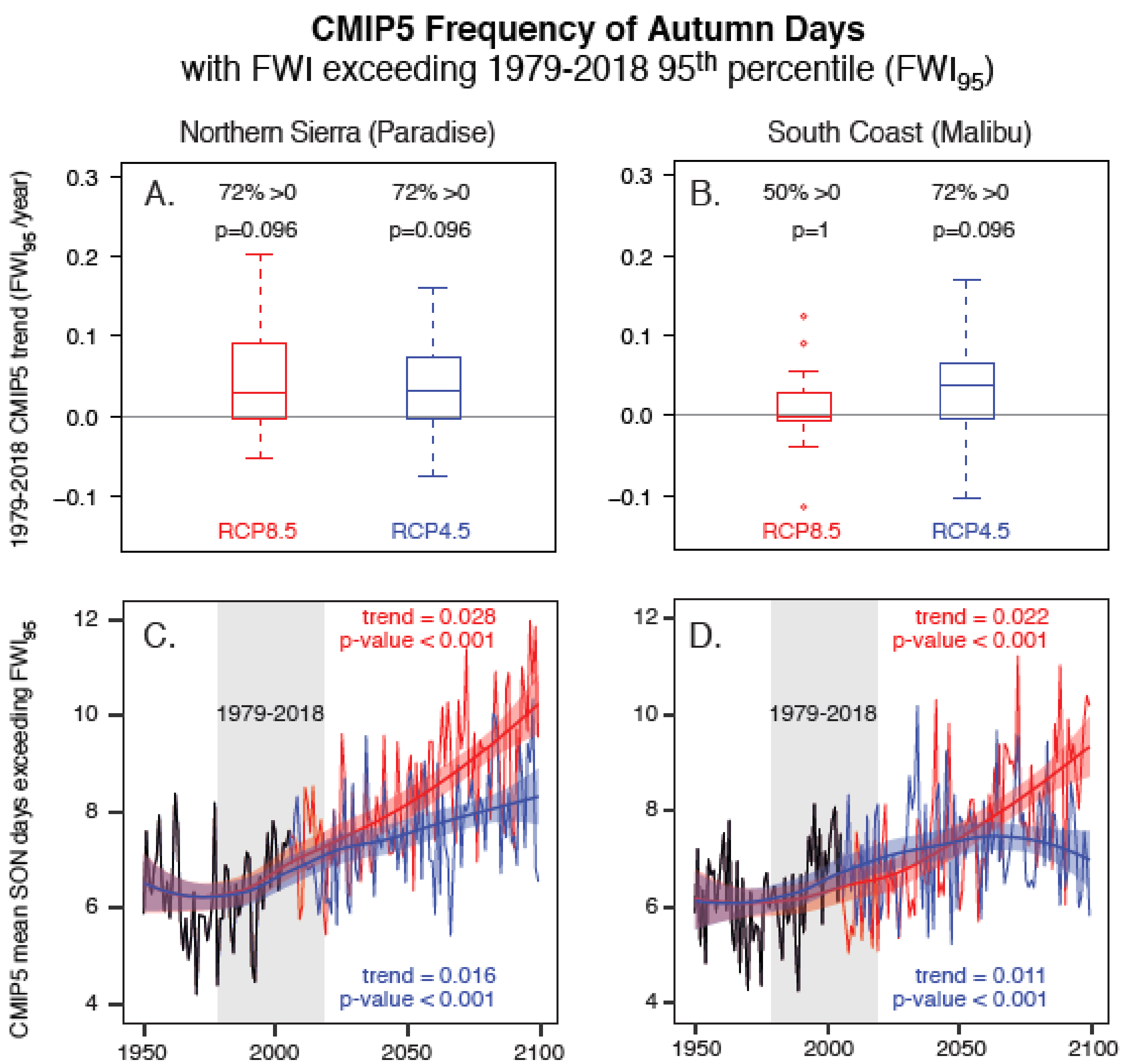

Figure 11 - Frequency of high/extreme fire weather days (FWI 95%) under climate change scenarios RCP 4.5 and RCP 8.5. The horizontal axis shows that data between 1979 and 2018 was included in the analysis, and the model projects changes out to the year 2100. Number of severe fire weather days per year is shown to substantially increase for more pessimistic climate scenarios. Reproduced from Goss, et. al. (Footnote 31).

5. NEXT STEPS

This section details what data would need to be assembled in order to apply power law fits to wildfire weather tranches and assemble a MAVF treatment based on fire weather tranches.

Component	Symbols	Difficulty	Source	Comments
Wildfire weather tranches and event rates.	t_i, F_0, f_i	Moderate	Academic, CA fires	Methodology for fire weather event severity has been developed by several groups.
Wildfire consequence distributions and means	dW_i/dA, α_i	Moderate	Academic, CA fires	Methodology for fire size distributions has already been developed by several groups.
Fires per event	π_i		Academic, CA fires	Will come out of tranche analysis.
Power line frequency multiplier	P_i	Moderate	Utility data, weather	Existing utility data is sufficient to show increase in outage/damage rates as a function of wind speed.
PSPS event severity	d_i	Easy	Utility SME, PSPS history	Once tranches & severity are established, extent of associated PSPS event can be calculated.
PSPS consequences and efficiency	S, Di, ε	Hard	Utilities, consultants, CPUC, intervenors	CPUC or WSD needs to develop methodology for quantifying customer harm.
Mitigations for wildfire and PSPS	w_i, q_i	Easy	Utilities	Utilities have mitigation estimates already, need to divide them into weather severity tranches if they depend on wind.

6. CONCLUSION

This whitepaper is intended to lay out a practical approach to incorporate the statistical properties of wildfires, which have consequences that follow power law statistics over several orders of magnitude, into the risk estimation framework adopted by the California Public Utilities Commission. It lays out the elements that need to be incorporated into the risk model, explains the rationale behind them, and discusses what pieces need to be created or assembled in order to create a proper risk model for utility wildfire losses. It is a framework more than it is a recipe: It is understood that IOUs may have or may obtain their own risk models and the S-MAP framework leaves a lot to utility discretion. A successful utility wildfire model, however, should have elements that can be mapped back to the principles laid out in this paper.

This paper also provides a technical framework for formalizing a requirement that the Commission and stakeholders have been attempting to enforce since the passage of ESRB-8: namely that utility power shutoff should be a "last resort" and that utilities should be trying to raise the thresholds at which they shut off power. It lays out a framework for implementing the cost-benefit analysis originally envisioned in D.09-09-030 within the auspices of the S-MAP Settlement Agreement using multi-attribute value function and its associated risk-spend efficiencies. The paper has tried to make clear the link between power law distributions and the dire risks of the most catastrophic wildfires and lays out a method by which these events can be isolated for treatment by power shutoff. At the other end of the risk spectrum, a process of continuous improvement should be undertaken that will raise utility shutoff thresholds and reduce the very significant risks and harms posed by PSPS.

Respectfully submitted this 1st day of February, 2020,

By: __*/S/*____***Joseph W. Mitchell***____________________

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Appendix B – Presentation – Power Law Statistics

WILDFIRE STATISTICS AND THE USE OF POWER LAWS FOR POWER LINE FIRE PREVENTION

Prepared for:
Mussey Grade Road Alliance
S-MAP II Phase 1 Track 1 Technical Working Group

February 3, 2021

Joseph W. Mitchell, Ph. D
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Prepared by M-bar Technologies and Consulting

- Power Laws
- Power Laws and Wildfire
- Power Laws, Wildfire, and Utilities
- Building a Risk Model
- Incorporating Extreme Events into MAVF
- Next Steps

Goal: Safe Utility Operation

The purpose of utility wildfire mitigation is to raise the fire weather severity limits at which utility equipment can be safely operated.

Critical Phenomena & Power Laws

- Landslides
- Earthquakes
- Species Extinction
- Wildfires
- 1/f Noise
- Etc…

Accumulation, Instability, Cascade

Per Bak

“self-organized criticality”

“complex behavior in nature reflects the tendency of large systems with many components to evolve into a poised, ‘critical’ state, way out of balance, where minor disturbances may lead to events, called avalanches, of all sizes. **<u>Most of the changes take place through catastrophic events</u>** rather than by following a smooth gradual path”

Power Laws

- Self-organized critical events show “power law” behavior

$$y = Cx^{-\alpha}$$

- Extreme events dominate the result. “Fat-tailed”
- For $\alpha < 1$, can’t even predict average from past events. This is important.

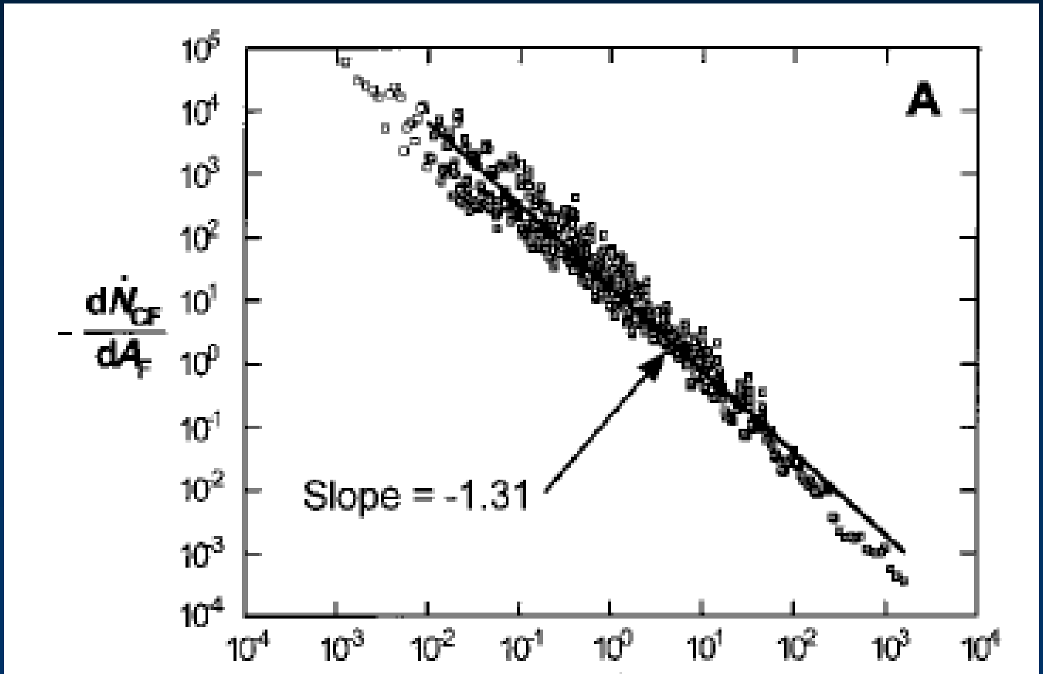
Wildfire and Power Laws

Malamud et. al, 1998

US Fish & Wildlife wildfires 1986-1995

Simple models reproduce behavior

<u>Shows as linear on log-log plot</u>



Malamud, B.D., Morein, G., Turcotte, D.L., 1998. Forest Fires: An Example of Self-Organized Critical Behavior. Science 281, 1840–1842.

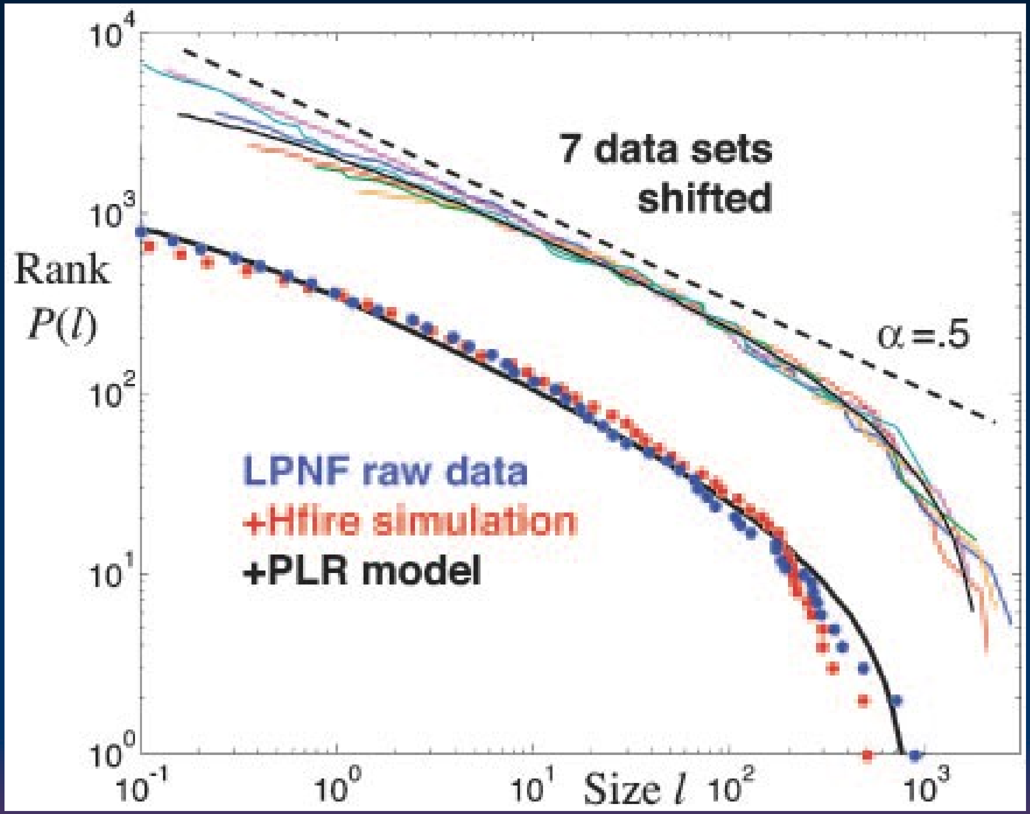
Power Law with Cutoff

Moritz et. al. 2005

- Larger data set
- PLR/HOT model

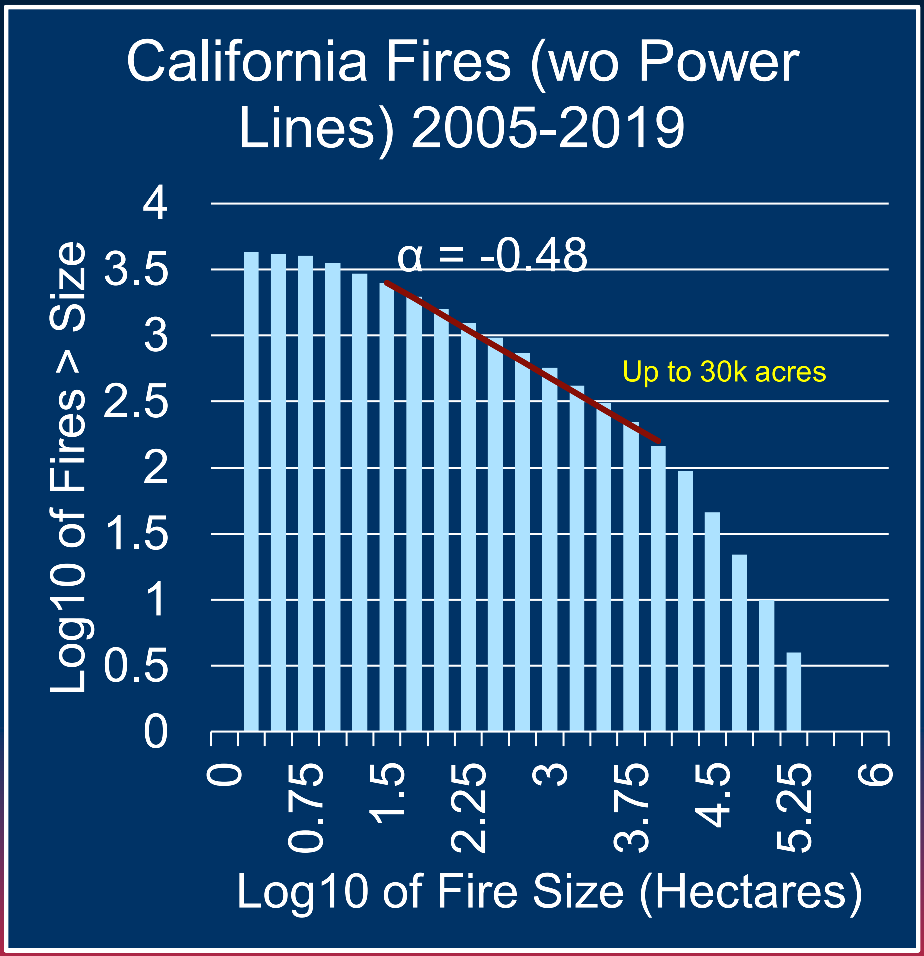
$$y = C[(a+x)^{-\alpha} - (a+L)^{-\alpha}]$$

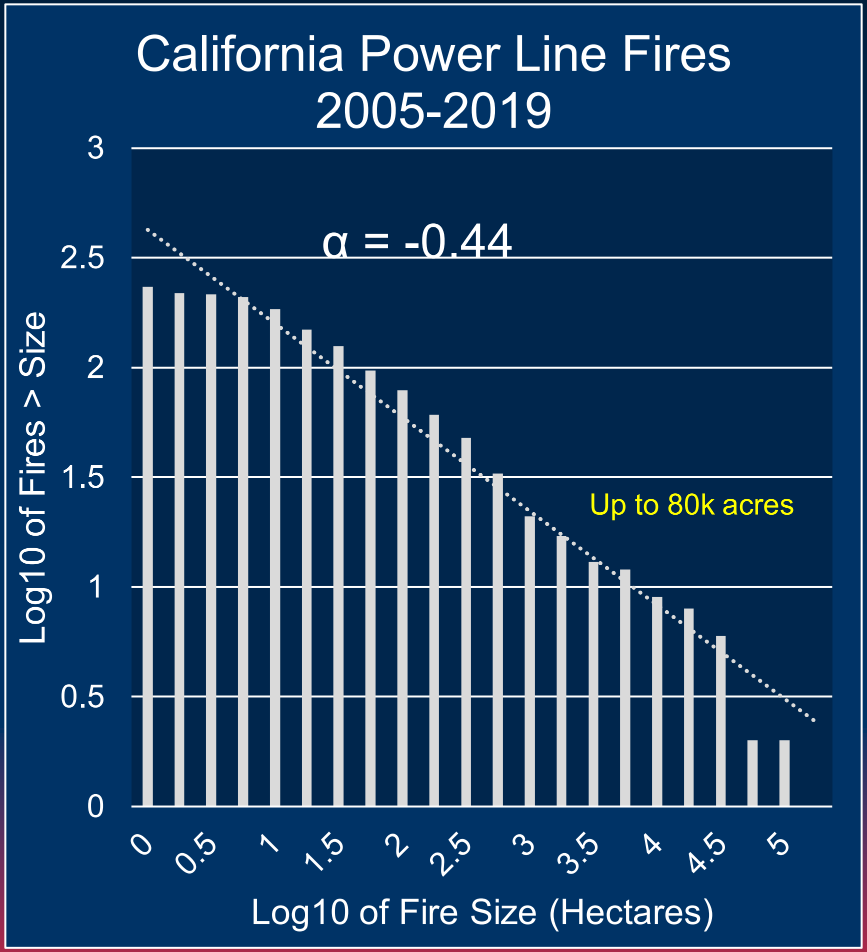
- Cutoff at large sizes (everything burns)
- **$\alpha < 1$ (!!!!!)**



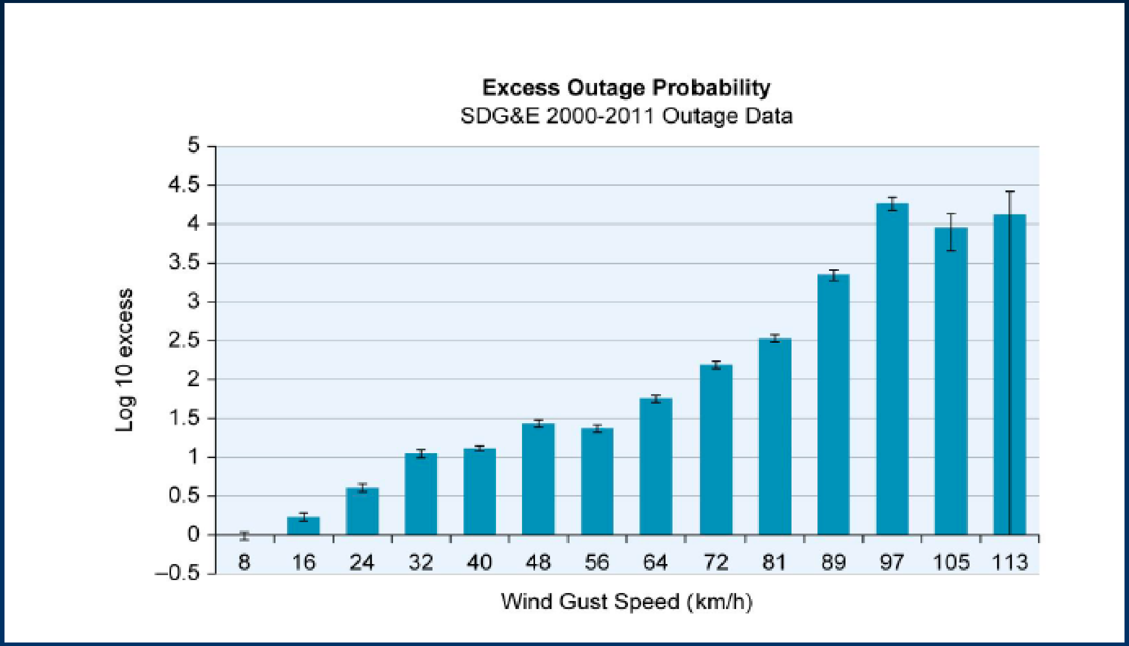
Moritz, M.A., Morais, M.E., Summerell, L.A., Carlson, J.M., Doyle, J., 2005. Wildfires, complexity, and highly optimized tolerance. Proceedings of the National Academy of Sciences 102, 17912–17917. https://doi.org/10.1073/pnas.0508985102

Power Line Fires





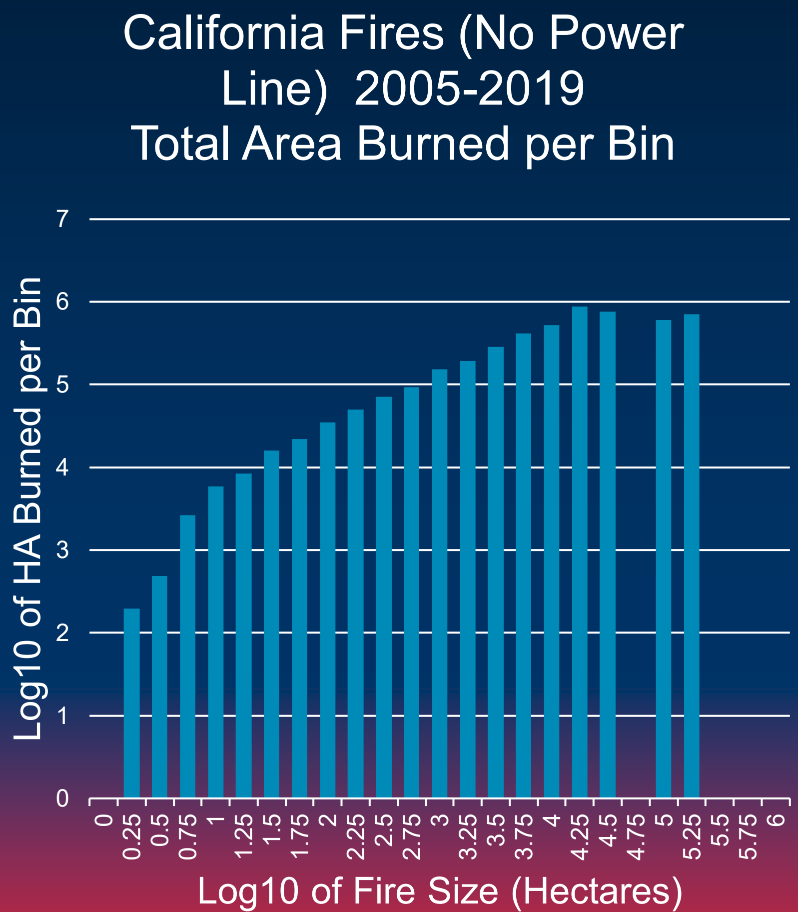
Power Lines and Wind

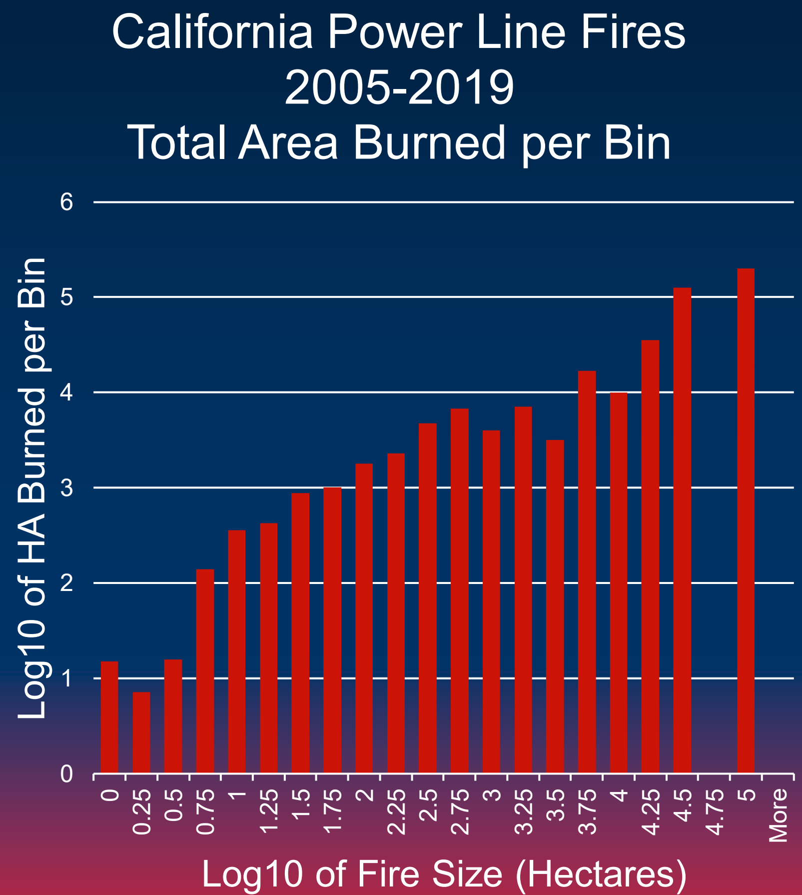


- Outages as proxy for ignition
- Wind gusts from nearest weather station
- Exponential growth with wind speed.

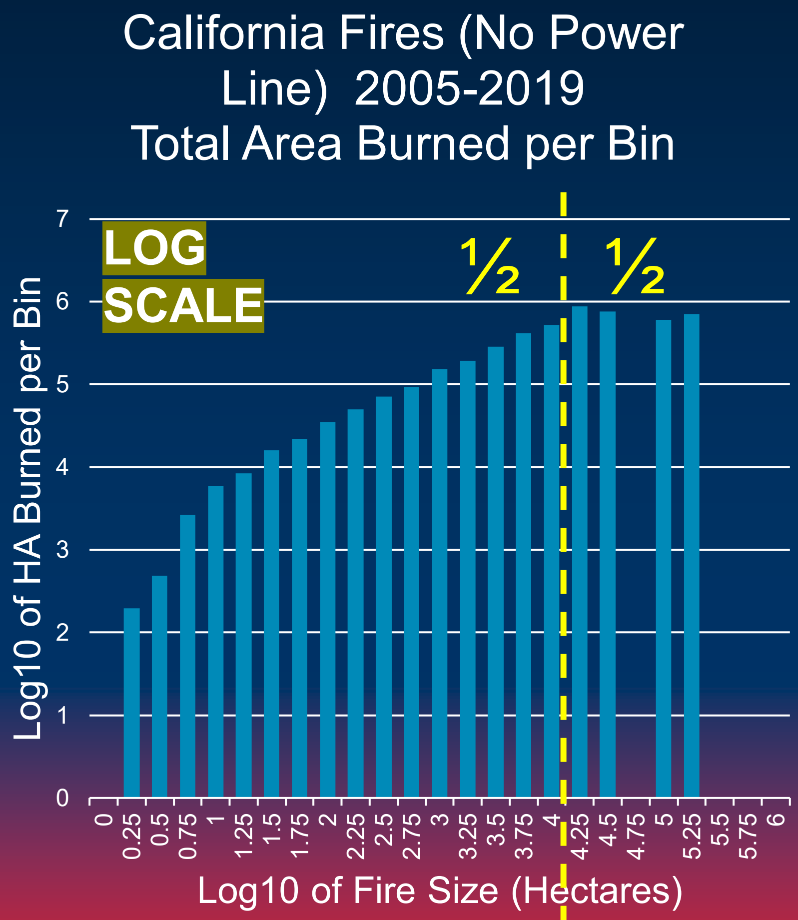
Mitchell, J.W., 2013. Power line failures and catastrophic wildfires under extreme weather conditions. Engineering Failure Analysis, Special issue on ICEFA V- Part 1 35, 726–735. https://doi.org/10.1016/j.engfailanal.2013.07.006

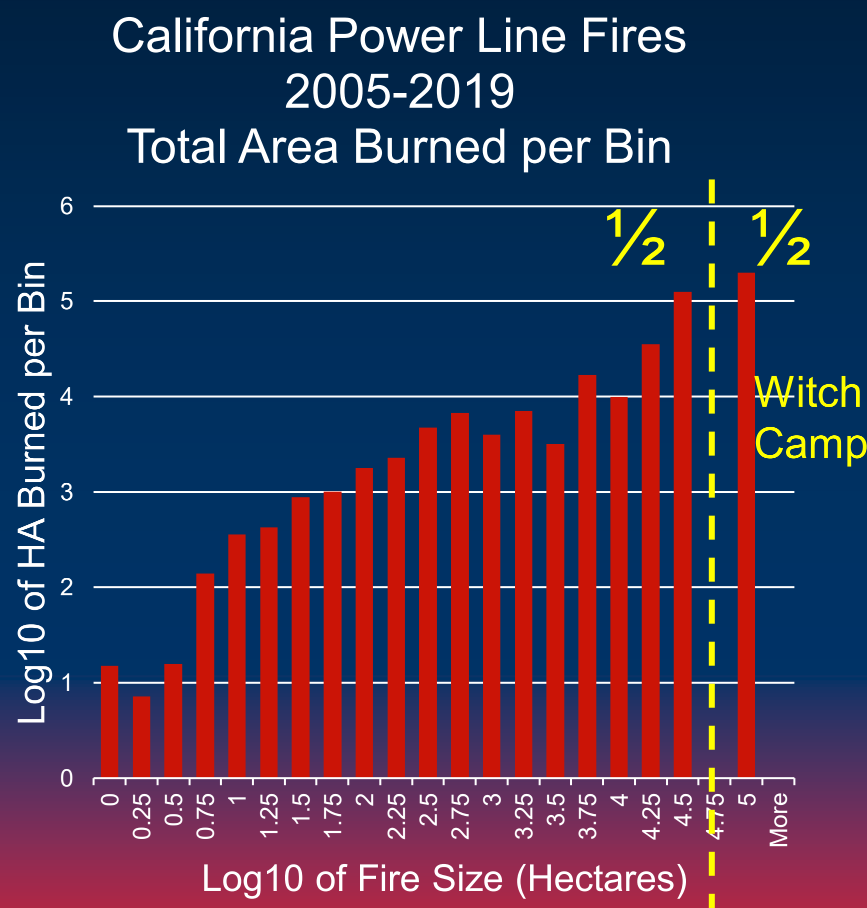
Area Burned as Risk Proxy





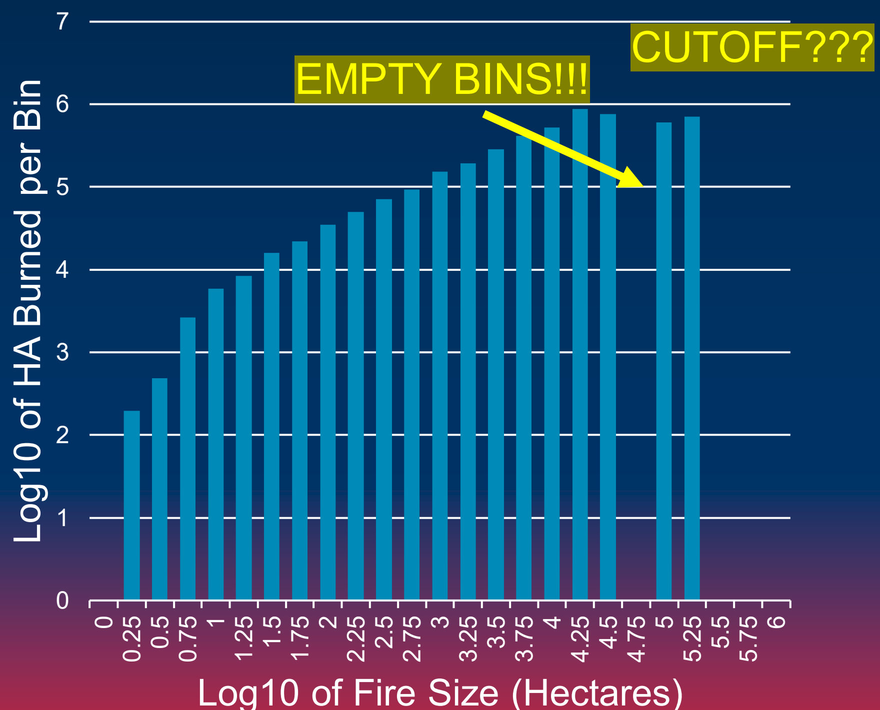
Area Burned as Risk Proxy



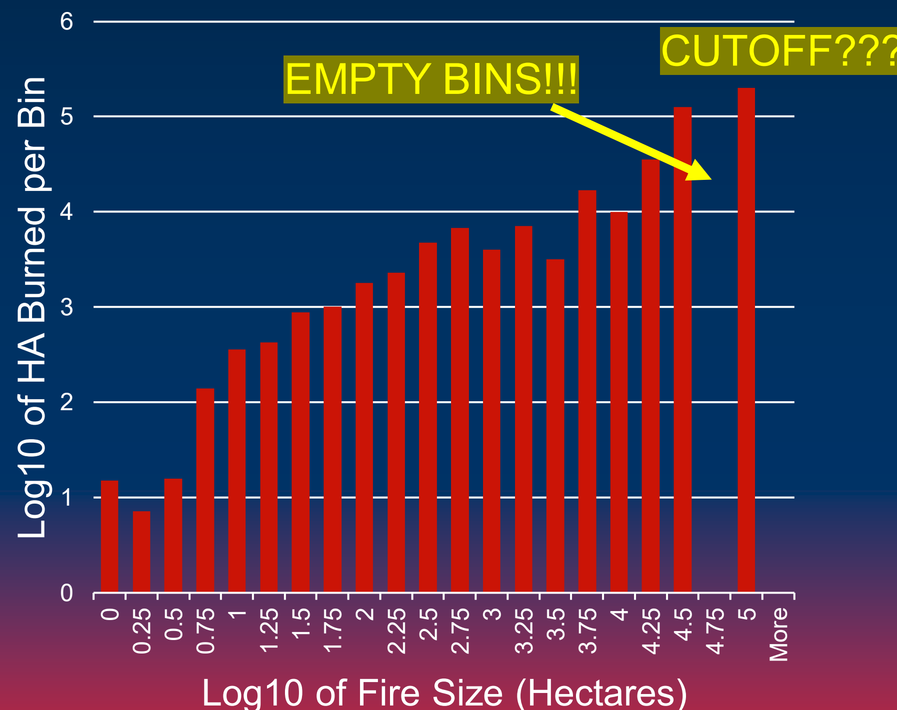


Uncertainty as Risk

California Fires (No Power Line) 2005-2019
Total Area Burned per Bin



California Power Line Fires
2005-2019
Total Area Burned per Bin



Summary of Problem

- Power line fires are more likely to ignite under extreme weather conditions.
- The greatest amount of future damage will come from the most extreme events.
- We know little about maximum size or frequency of extreme fires, making risk estimates uncertain.

Proposal:

Optimized mitigation with heuristic kill-switch

- Weather event as risk event
- Extreme event risks and uncertainties managed by PSPS
- Reduce PSPS for lower risk tiers
- i.e.: What’s happening now except formalized to improve:
  - Customer experience
  - Regulatory supervision
  - Spending priorities

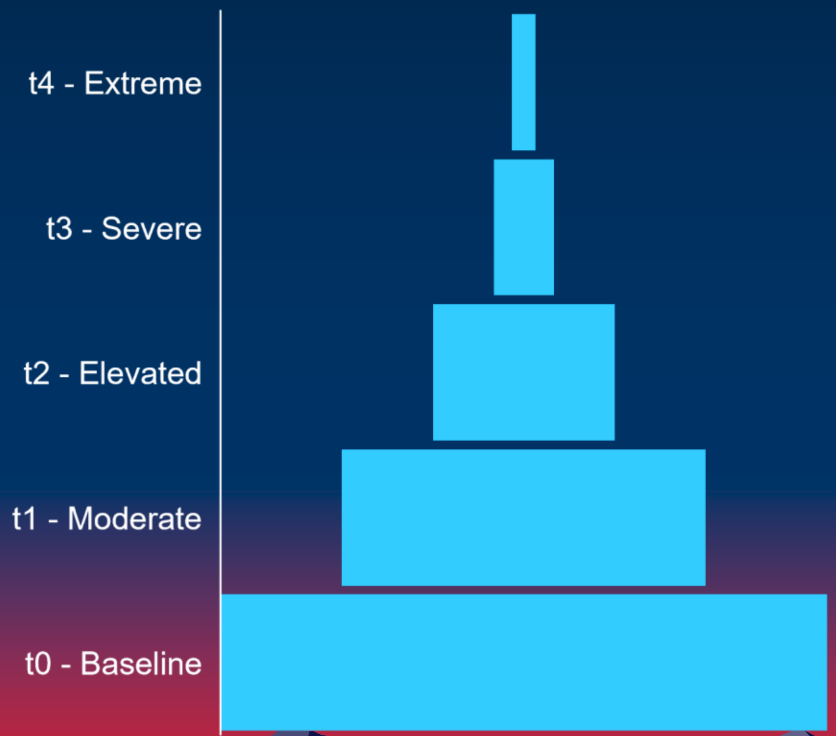
Proposal:

Optimized mitigation with heuristic kill-switch

- Can be done in MAVF framework
- Weather Risk Event Advantages:
  - Allows PSPS risks to be treated in same way as wildfire risks
  - Captures increased risk of utility ignitions
  - Allows clear mitigation goals to be set
  - Allows straightforward use of climate inputs

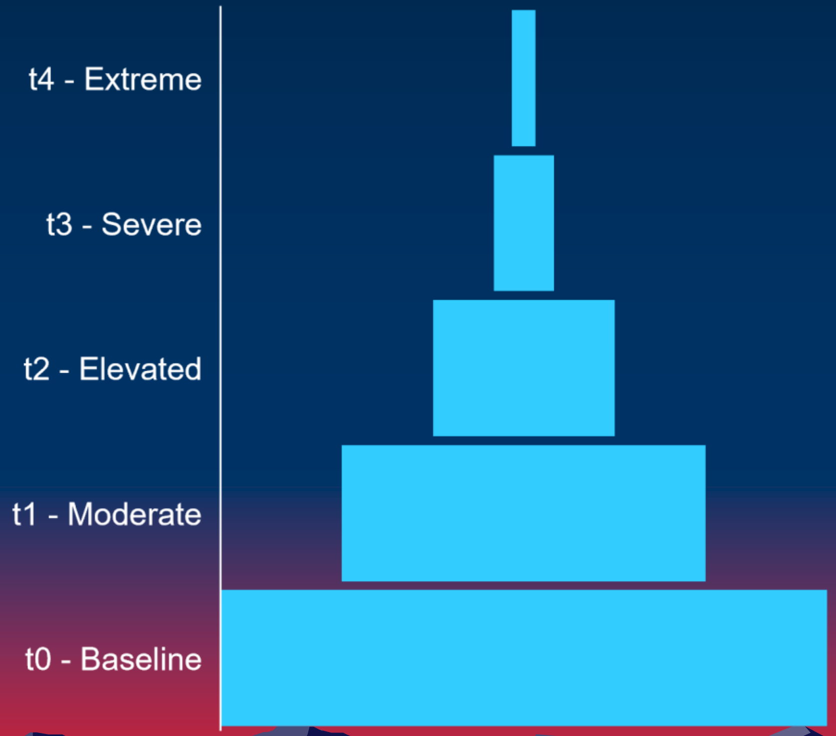
Fire Weather Tranches

Wildfire weather intensity tranches, based on frequency



Wildfire weather intensity tranches, based on risk

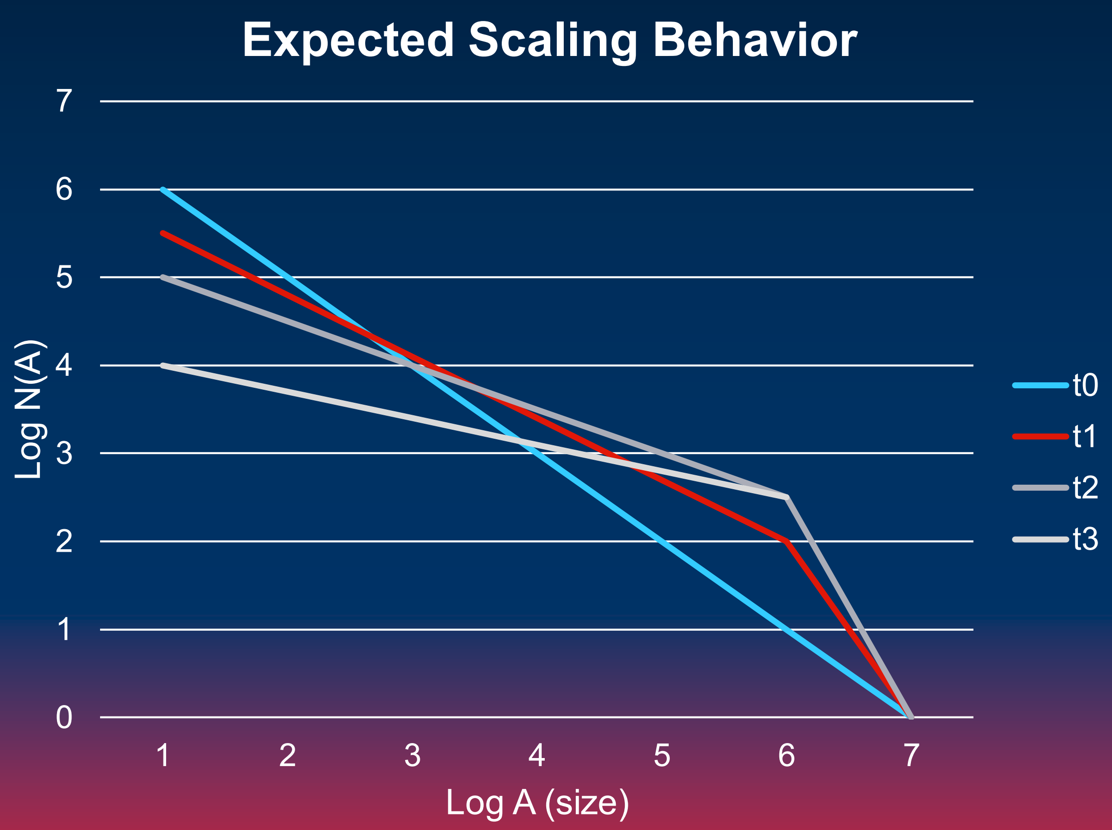
Fire Weather Tranches



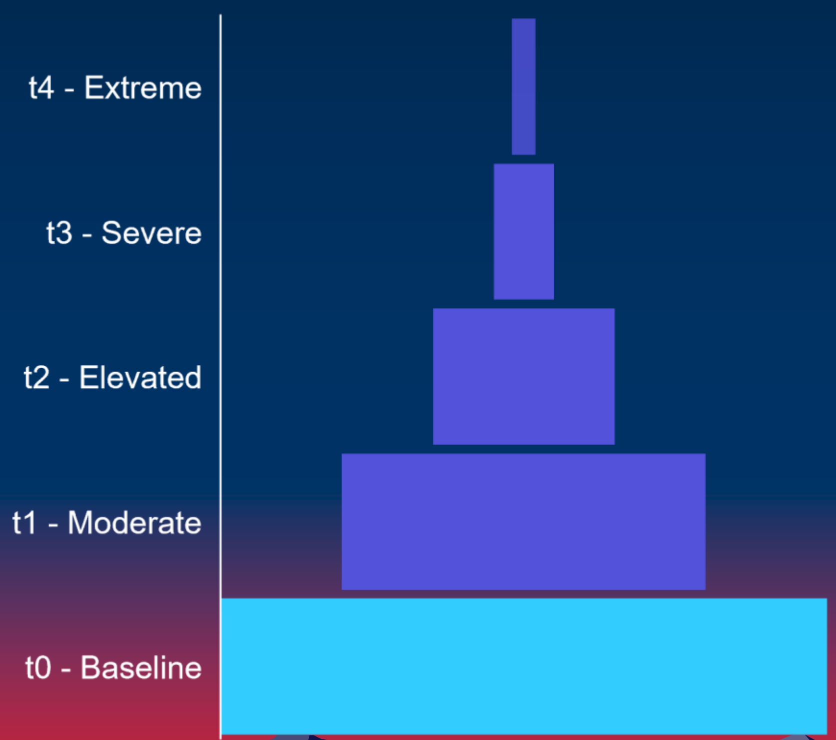
- Weather events
  - Meteorological (Abatzoglou)
  - Fosberg Fire Weather Index
  - SAWTI
  - FPI
  - Measured

Wildfire Sizes vs. Weather Event Severity

- Group all wildfires into weather tranches
- “Baseline” tranche t0 – no weather effects
- Tranches t1,t2,t3 from moderate to extreme



Fire Weather Tranches

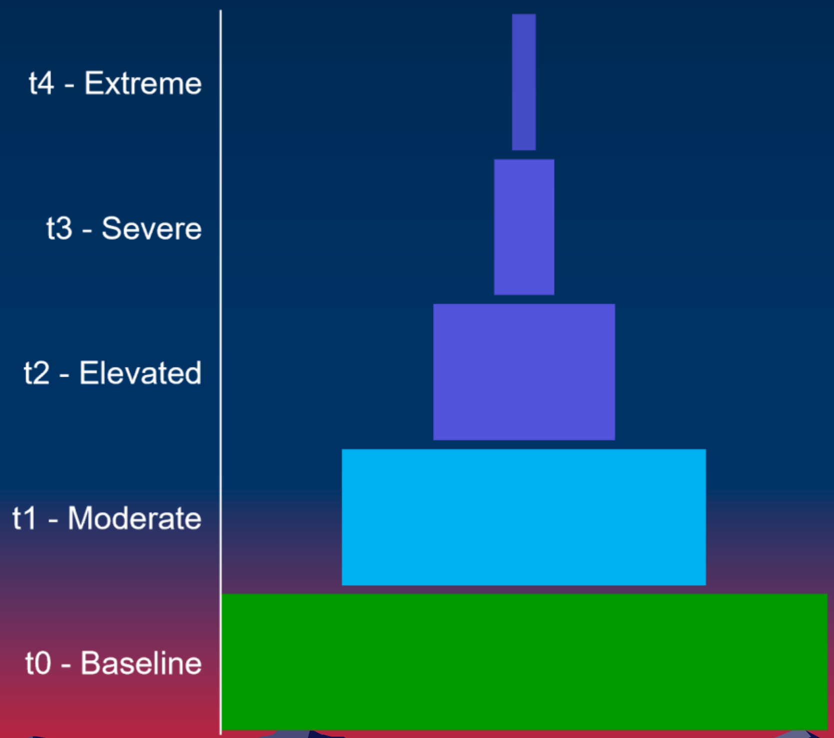


Current Utility Response

--- PSPS for elevated wildfire risk

--- Mitigation for baseline risk

Fire Weather Tranches



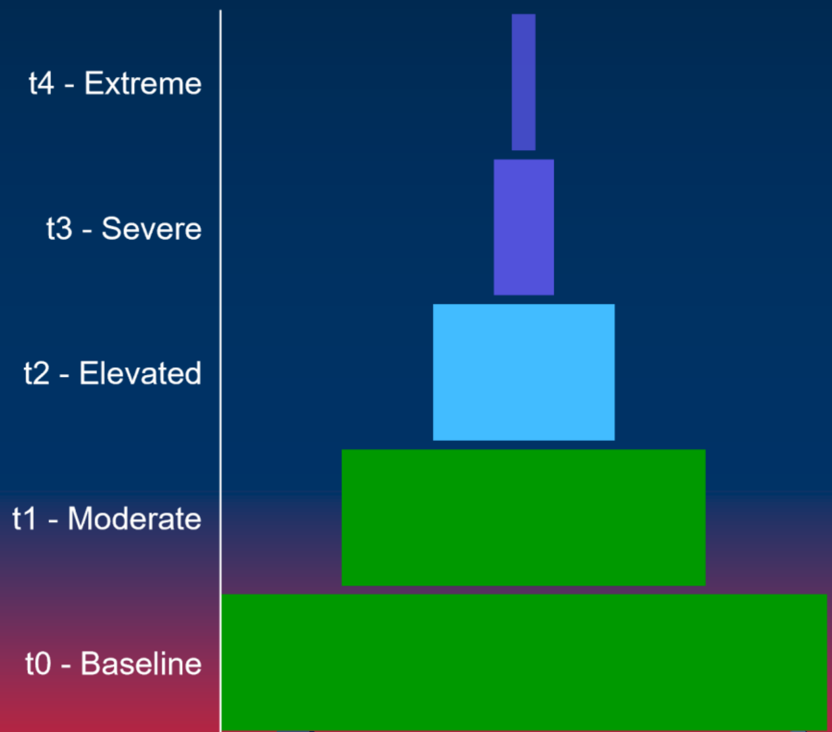
Short-Term Goal

--- PSPS for severe wildfire risk

--- Mitigation for moderate tranche, raise PSPS threshold

--- Safe operation for baseline risk

Fire Weather Tranches



Medium-Term Goal (example)

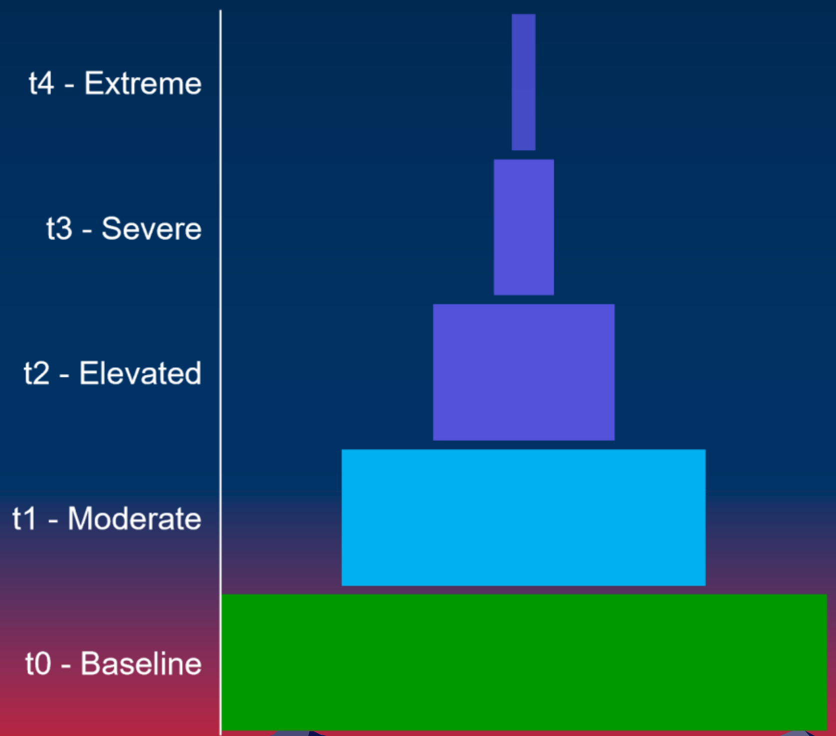
--- PSPS for severe wildfire risk

--- Mitigation for severe tranche,

--- Safe operation for moderate and baseline risk

Fire Weather Tranches

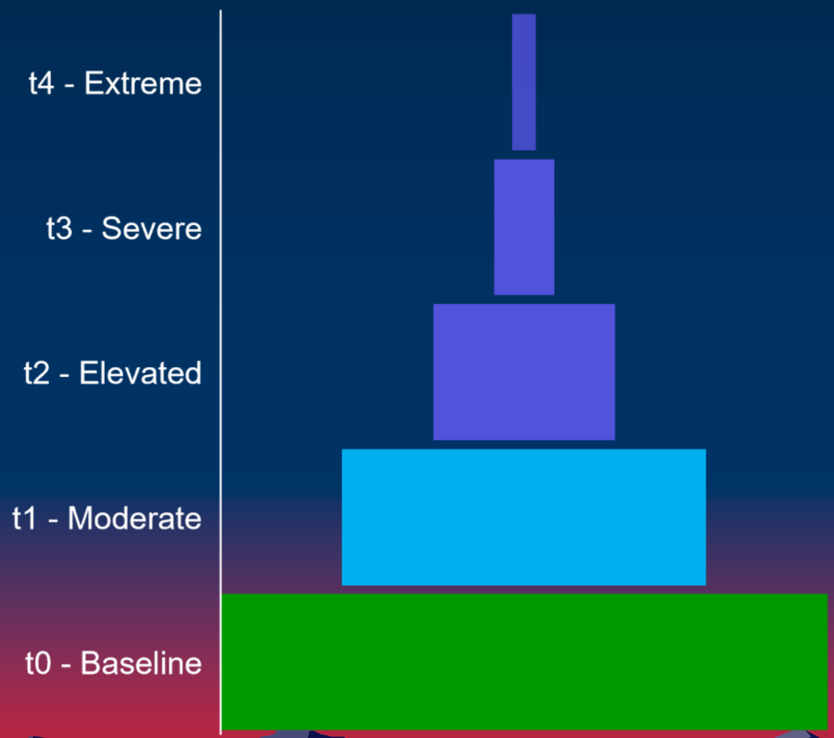
Risks



--- PSPS risks (reliability, safety risks)

--- Residual wildfire ignition after mitigation

Fire Weather Tranches



Mitigations

--- PSPS mitigations (notification, microgrid, restoration)

--- Weather-sensitive ignition

--- Wildfire ignition risks

PSPS – Dangers on Both Ends

PSPS Hazards
(w. alleged examples)

- Economic Losses
- At-risk Individuals
- Loss of Communications (San Anselmo house fire fatality)
- Generator fires (Thief fire)
- Cooking fires (Tick fire)
- Auto accidents (PG&E claims)

Wildfires Before/During/After PSPS
(w. alleged electrical involvement)

Fire	Date	Utility
Camp	November 8, 2018	PG&E
Kincade	October 23, 2019	PG&E
Zogg	September 27, 2020	PG&E
Silverado	October 26, 2020	SCE
Cornell	December 7, 2020	SCE

Elements of the MAVF

- **Tranches: $t_i \ldots t_N$**
- **Baseline Tranche: t_0**
- **Baseline Wildfire Rate: F_0**
- **Fire Weather Event Frequency: f_i**
- **Fire Multiplier: π_i**

  Fires per weather event

- **Tranche Wind Speed: v_i**

  Not ideal. Will be broad range of wind speeds

Elements of the MAVF

- **Power Line Frequency Multiplier: P_i**
  Increase of ignition rate for each severity ranking
- **Wildfire Consequence Distribution: dW_i/dA_i**
  Probability distribution – used for Monte Carlo
- **Wildfire Consequence Mean: $\overline{W}_i$**
- **Cutoff Size: $A_{max,i}$**
- **Minimum Reliable Size: A_{min}**
- **Power Law Exponent: α_i**

Elements of the MAVF

- **De-energization Severity: d_i, $i > 0$**

  How extensive is PSPS, geographically & in time?

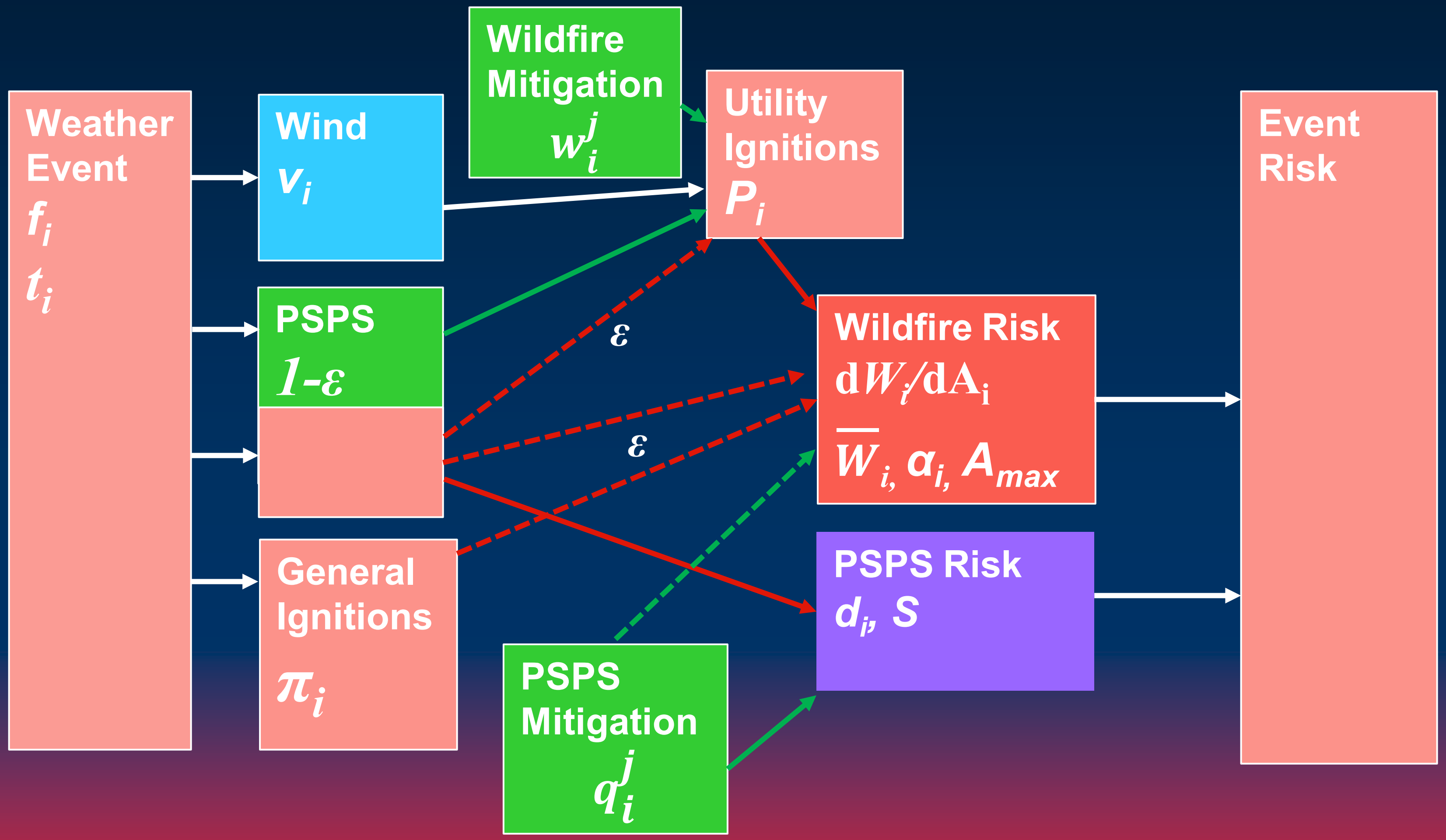
- **De-energization Consequences: $D_i = Sd_i$**

  S is PSPS harm per customer per hour - TBD

Elements of the MAVF

- **De-energization Inefficiency:** ε
  - *Risk from PSPS fires (generators, cooking, etc.)*
  - *Risk from de-energizing in wrong place*
  - *Increased risk from all wildfires (communication, etc.)*
- **Wildfire Mitigation Efficiency:** w_i^j
- **De-energization Mitigation Efficiency:** q_i^j

Where Pieces Fit



And the Math

- Power line wildfire risk:

$$R_i = f_i \pi_i P_i \overline{W}_{\mathrm{I}}$$

- PSPS risk:

$$R_i = R_i^{PSPS} + R_i^{WF} = f_i(D_i + \pi_i \varepsilon_i P_i \overline{W}_i)$$

Safe Operation Threshold

- Safe operation without PSPS:

$$\pi_i(1-\varepsilon_i)P_i\overline{W}_i > D_i$$

- Safe operation with mitigation (ex. Tier 2):

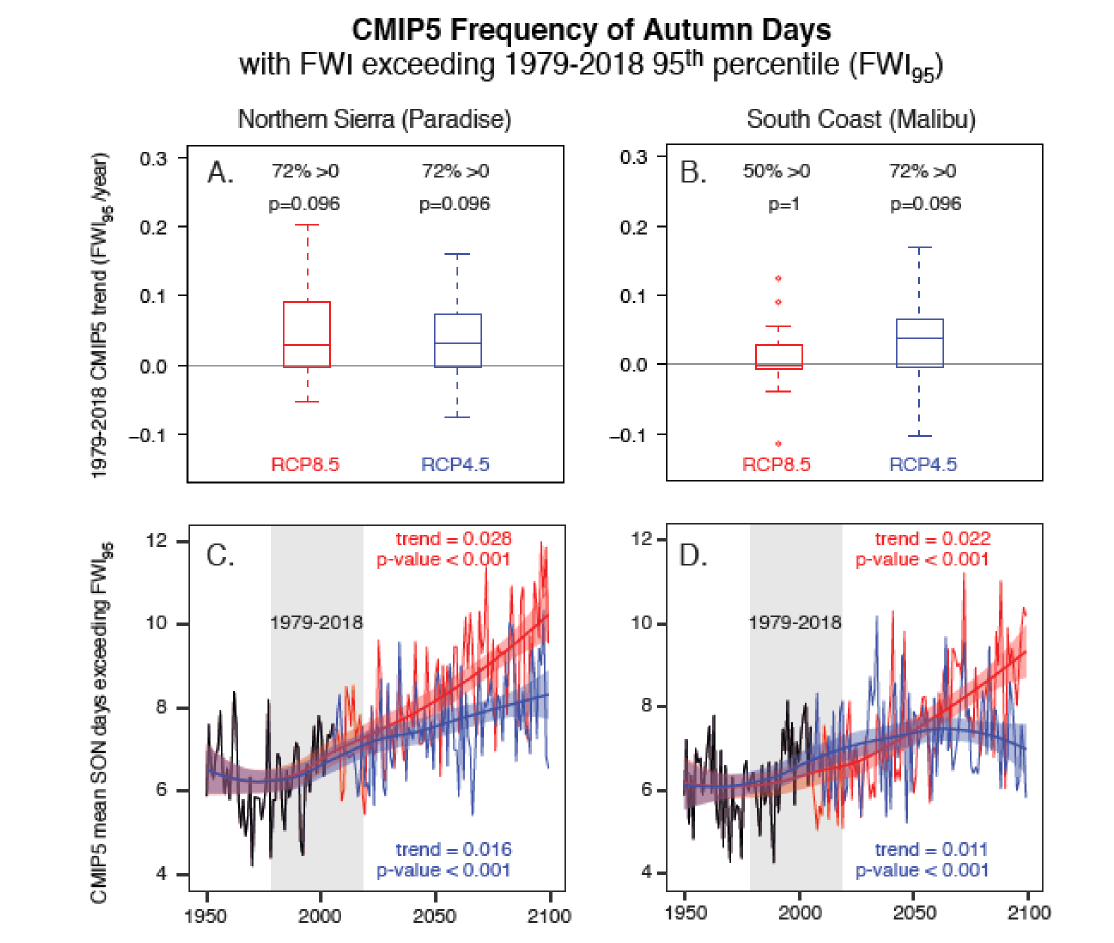
$$\prod_{j=1}^{W}(1-w_2^j)(1-\varepsilon_2)\pi_2 P_2\overline{W}_2 < \prod_{j=1}^{Q}(1-q^j)D_2$$

Other issues

- Climate change
- Attributes
- Other Tranches

Increase in Extreme Fire Weather Frequency Due to Climate Change

Changes f_i



Goss, M., Swain, D.L., Abatzoglou, J.T., Sarhadi, A., Kolden, C., Williams, A.P., Diffenbaugh, N.S., 2020. Climate change is increasing the risk of extreme autumn wildfire conditions across California. Environ. Res. Lett. https://doi.org/10.1088/1748-9326/ab83a7

Other MAVF Questions

- How do we divide into attributes?
  - TBD but should be straightforward
- What about other tranche definitions?
  - Should be fine, subdivide each into fire weather severity tranches.
- Monte Carlo or Averages?
  - Monte Carlo can deal with correlated risks

Next Steps

Component	Symbols	Difficulty	Source	Comments
Wildfire weather tranches and event rates.	t_i, F_0, f_i	Moderate	Academic, CA fires	Methodology for fire weather event severity has been developed by several groups.
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PSPS consequences and efficiency	S, Di, ε	Hard	Utilities, consultants, CPUC, intervenors	CPUC or WSD needs to develop methodology for quantifying customer harm.
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Thank you

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SUPPLEMENTAL SLIDES

Frequency vs Probability